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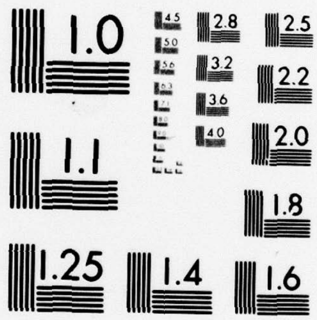

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EFFICIENCY OF AN ADAPTIVE INTER-SUBTEST BRANCHING STRATEGY IN THE MEASUREMENT OF CLASSROOM ACHIEVEMENT

(12)

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and
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A real-data simulation was conducted to investigate the efficacy of an adaptive testing strategy designed for achievement test batteries applied to a classroom achievement test. This testing strategy combined adaptive item selection routines both within and between the subtests of the test battery. Comparisons were made between the conventionally administered tests and the simulated adaptive tests in terms of test length, psychometric information, and correlations of achievement estimates. Design of the study also permitted (1) separation of the effects of the adaptive intra-subtest item selection

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procedure and inter-subtest branching, (2) evaluation of the effects of different intra-subtest termination criteria, (3) use of classical regression equations and regression equations corrected for errors of measurement in the predictors, and (4) cross-validation stability of the inter-subtest branching regression predictions. Data consisted of the responses from 1,600 students to classroom-administered final exams in a general biology course at the University of Minnesota.

Total test length was reduced from 16% to 30% using the adaptive intra-subtest item selection strategy with a variable termination criterion that omits those items providing little information to the measurement process. Subtest-length reductions ranged from about 8% to 62%. Total test length was reduced another 1% to 5% (with subtest-length reductions of up to 53%) upon the addition of an inter-subtest branching strategy that utilized regression equations with prior information concerning a student's performance.

Reductions in subtest length were accomplished with virtually no loss in psychometric information. Correlations between the Bayesian achievement estimates from the adaptive and conventional tests were uniformly high, typically r=.90 and higher. Results showed that the use of the corrected regression equations did little to improve the performance of the inter-subtest branching; although the multiple correlations for the corrected equations were higher, both the information curves and correlations of achievement estimates were generally lower. Cross-validation results indicated that the procedure can be used in different samples from the same population.

Results from this study generally supported the generality of this adaptive testing strategy for reducing achievement test length with no adverse impact on the quality of the measurements. Suggestions are made for further research with this testing strategy.

CONTENTS

CONTENTS, continued

Acknowledgments

Data utilized in this report were obtained from volunteer students in General Biology, Biology 1-011, at the University of Minnesota, during fall quarter 1977 and winter quarter 1978; appreciation is extended to these students for their participation in this research. The cooperation of Kathy Swart and Norman Kerr of the General Biology staff in providing access to the students, as well as their encouragement and contributions of time and ideas to this research program, are deeply appreciated.

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Efficiency of an Adaptive Inter-Subtest Branching Strategy in the Measurement of Classroom Achievement

The development of adaptive testing technology has traditionally taken place within the context of ability measurement. Indeed, much of the adaptive testing research has been concerned with the application of the various adaptive testing strategies to the measurement of a single unidimensional ability domain (e.g., Betz & Weiss, 1974, 1975; Larkin & Weiss, 1974, 1975; Lord, 1977; McBride & Weiss, 1976; Urry, 1977; Vale & Weiss, 1975; Weiss, 1973). More recently, Bejar and Weiss (1978); Bejar, Weiss, and Gialluca (1977); Bejar, Weiss, and Kingsbury (1977); and Kingsbury and Weiss (1979) have demonstrated the applicability of these unidimensional adaptive testing strategies to the measurement of classroom achievement. Frequently, however, achievement tests include items drawn from several distinct content areas. Hence, the assumption of unidimensionality of the entire set of items constituting an achievement test may be untenable, and the application of unidimensional testing strategies inappropriate.

Although Reckase (1978) has shown that the first factor of a multidimensional achievement test will be related to the item characteristic curve (ICC) item parameter estimates from the three-parameter ICC model, in many cases the first factor will account for only a small portion of the common variance of the achievement test items, and even smaller portions of the total variance of the test. Thus, application of a unidimensional ICC model to a multidimensional achievement test will result in achievement level estimates that reflect achievement on only a small subset of course content. In addition, the diagnostic information regarding a student's performance on specific course content areas is lost to both student and instructor by measuring achievement on only one dimension.

In an attempt to design an adaptive testing strategy that would reduce testing time, yet retain the capability of providing students and instructors with scores on the separate subtests in an achievement domain, Brown and Weiss (1977) proposed a testing strategy specifically designed for achievement test batteries that are composed of multiple content areas. It included provisions for adaptive branching between subtests as well as for adaptive item selection within subtests, in an attempt to adapt the test battery to each examinee most efficiently. Brown and Weiss (1977) applied the combined inter-subtest and intra-subtest adaptive strategy in a real-data simulation using a military achievement test battery. They observed a mean reduction in test battery length of nearly 50%, accompanied by a minimal loss in psychometric information.

Purpose

The present study investigated the efficacy of this adaptive testing strategy when it was applied to a classroom achievement test in a different kind of testing environment. Further, this study evaluated the relative contributions of the intra-subtest item selection and inter-subtest branching strategies in

terms of

1. The number of items administered in each subtest of the battery and in the test as a whole,
2. Reduction in test length when compared to the length of a conventionally administered examination,
3. Correlations between achievement estimates derived from the adaptive strategies with those obtained from the conventional examination, and
4. Effects of adaptive administration on psychometric information.

In addition, this study included an investigation of the effects of using the adaptive inter-subtest branching strategy developed from one set of data on a different data set, using a double-cross-validation design.

METHOD

Procedure

Test Items and Subjects

Real-data simulation techniques were applied to the item responses of 800 students who were administered the final examination in General Biology, Biology 1-011, an introductory lecture and laboratory class at the University of Minnesota, during the fall academic quarter of 1977, and to the responses of another 800 biology students from winter quarter of 1978.

Each of these final examinations was 110 items long and was administered conventionally by paper and pencil at the end of the academic quarter. However, each student was directed to answer only 100 of the questions and was free to omit any 10 items of his/her choice. Additionally, only the responses to those items from five content areas--Chemistry, Cell, Energy, Reproduction, and Ecology--were used for this study. The numbers of items in each content area differed slightly across the two quarters; the distribution of items across content areas for the two quarters is shown in Table 1. Each of these five content areas formed a subtest used for the branching strategy discussed below.

Item Parameterization

Items were parameterized within content areas using Urry's (1976) ESTEM computer program for latent trait item parameterization employing the three-parameter logistic model. This program provides estimates of the ICC item discrimination (a), item difficulty (b), and lower asymptote (c) parameters.

Urry's item parameterization program calculates item parameter estimates using a two-stage procedure. In the first stage, initial item parameter estimates are determined for all items. However, these initial item parameter estimates are not reported for an item if one or more of the following conditions holds: (1) $a < .80$, (2) $b < -4.00$, (3) $b > 4.00$, or (4) $c > .30$. In the second stage, item parameters are recomputed for all items that are not excluded by the criteria applied in the first stage. In this stage, item parameter estimates are reported without restrictions (e.g., c may be greater than .30 for some items in the second stage) for all items not excluded in the first stage.

The items were parameterized at the peak of training; that is, items in each content area were parameterized using test data obtained soon after in-

struction in that content area took place. Items in content areas Chemistry, Cell, and Energy were parameterized at the time of Midquarter 1 (MQ1), and items in content areas Reproduction and Ecology were parameterized at the time of Midquarter 2 (MQ2). Item parameter estimates were obtained from classroom examination data from winter quarter of 1976 through spring quarter 1977. The minimum sample size for parameter estimation for any one item was 844; most item parameter estimates were based on data from 1,000 to 2,000 students.

Conventional Test

A conventionally administered test was used for comparison with the adaptive testing strategies. The subtests were administered in the same order for both the conventional and adaptive strategies. In the conventional test all items within each subtest were administered sequentially, with all students taking all the items, and all items were administered in the same order. There was, then, no differential entry point for the subtests when administered conventionally. Bayesian scoring (Owen, 1975) was used for each of the conventional subtests, using a mean of 0.0 and a prior variance of 1.0 as the initial prior estimate of the Bayesian score for each subtest.

Adaptive Tests

As in the Brown and Weiss (1977) study, an adaptive testing strategy utilizing both inter-subtest adaptive item selection and intra-subtest branching was used, in conjunction with a variable termination criterion. This was done in order to reduce to a minimum the number of items administered to each student, while causing minimal change in the measurement characteristics of the whole test.

As in the conventional test, a Bayesian achievement estimate ($\hat{\theta}$) was obtained for each student after the administration of every item. Item selection within each subtest was based on the concept of item information as described by Birnbaum (1968). Items were selected within a subtest for each student by computing the value of item information for every unadministered item at the current level of $\hat{\theta}$ for that student. The item selected for administration was the item that had the highest item information value at that level of $\hat{\theta}$; once an item was administered to a student, it was eliminated from the subtest pool of available items for that student. The selected item was administered, the student's response was scored, and a new θ estimate was obtained. Then a new item was selected, and the procedure was repeated.

Testing continued within each subtest until one of the following conditions occurred: (1) all the items within the subtest pool were administered; or (2) no item remaining in the pool provided information at the current level of $\hat{\theta}$ that exceeded some predetermined small amount of information. Two such values of information were used in this study: .01 and .05. Further detail regarding item selection and achievement estimation can be found in Brown and Weiss (1977).

Inter-Subtest Branching

Subtest ordering. Following the proposal by Brown and Weiss (1977), linear multiple regression was used to determine the order of administration of the subtests. Brown and Weiss, however, ordered subtests based on the linear regres-

sion of number-correct scores. In this study a Bayesian achievement estimate, using an assumed normal prior distribution with a mean of 0.0 and a variance of 1.0, was calculated for each student on each of the five subtests of the final examination. These five scores were then intercorrelated, and their intercorrelation matrix was used as the basis for inter-subtest branching. This procedure was used for the data from each of the two academic quarters separately.

The highest bivariate correlation was selected from this intercorrelation matrix (for each quarter), and one of the two subtests was arbitrarily designated to be administered first; the other was administered second. Multiple correlations were then computed using these two subtests as predictor variables and each of the other subtests, in turn, as the criterion variable. The subtest having the highest multiple correlation with the first two subtests was designated as the third test to be administered. This procedure was repeated to select the fourth subtest to be administered, selecting that subtest which had the highest multiple correlation with the previous three subtests. This process was continued until all five subtests were ordered and was repeated separately for each of the two quarters.

Differential subtest entry points. After administration of the first subtest, each student's entry points for the second and subsequent subtests were differentially determined. For the first subtest each student's prior achievement level was assumed to be $\hat{\theta} = 0.0$. That is, it was assumed that the student's achievement level was at the mean of the estimated θ distribution, since there was no previous information to indicate otherwise. The initial item administered from the first subtest was that item providing the most information at $\hat{\theta} = 0.0$; hence, all students began the first subtest with the same test item.

The entry point into the item pool for the second subtest was determined from the bivariate regression of scores from Subtest 2 on Subtest 1 and the student's $\hat{\theta}$ at the end of Subtest 1 ($\hat{\theta}_1$). The value of $\hat{\theta}_1$ for each student was entered into the bivariate regression equation for predicting the second subtest score from the score on the first subtest. This yielded an estimate for that student's score on Subtest 2, which was then used as the initial Bayesian prior $\hat{\theta}$ for intra-subtest item selection in Subtest 2. The item that provided the most information at this predicted level of θ was administered as the first item in the second subtest. The squared standard error of estimate from the bivariate regression equation was used as an estimate of the initial Bayesian prior variance of this entry-level achievement estimate.

Determination of the entry point for the third and subsequent subtests was simply a generalization of the method used for the second subtest. In general, the student's final achievement level estimates from all n previously administered subtests were entered into the multiple regression equation for predicting the next (n + 1st) subtest score from scores on the previous n subtests. This predicted achievement level estimate was used as the initial Bayesian prior $\hat{\theta}$ for intra-subtest branching within that subtest. The squared standard error of estimate from each regression was used as the initial Bayesian prior variance for each subtest.

Corrected regression equations. In addition to the classical multiple regression equations, a second set of equations was used to determine entry-level achievement estimates for each subtest. This second set of equations was applied to the data from fall and winter final exams in exactly the same manner as described above; the only difference between the two procedures was in the

way the equations were obtained. The results from use of the two kinds of regression equations were then compared.

The use of the second set of regression equations was studied because classical regression techniques were somewhat inappropriate for this set of data. In the general linear model of regression, the expected value of the dependent variable y is expressed as the "best" (in the least squares sense) weighted sum of p independent variables $x_i (i=1, \ldots, p)$. It is assumed that y is randomly distributed with n independent observations $y_j (j=1, \ldots, n)$, with common variance σ^2, and that the independent variables x_i are measured without error (Neter & Wasserman, 1974).

However, the original Bayesian $\hat{\theta}$ values used in this regression, obtained for each subtest of the final exam, were not measured without error. Indeed, for each of these Bayesian estimates, there was a corresponding value for the Bayesian posterior variance, which can be interpreted as an index of the variation inherent in the estimate itself. Hence, any classical regression procedure using these estimates is somewhat in error.

Lawley and Maxwell (1973) and Maxwell (1975) have discussed the effects such errors have on the regression equation and the multiple correlation coefficient. In their discussions, the general linear equation is expressed as

$$y_j = \alpha + \beta_1 (x_{j1} - \bar{x}_1) + \ldots + \beta_p (x_{jp} - \bar{x}_p) + e_j, \qquad [1]$$

where

α is a constant;
β's are the partial regression coefficients;
$\bar{x}_i$ is the mean of x_{ji} over all j; and
e_j is the random error of measurement in y_j.

The estimation equation, found by the method of least squares (where $\Sigma_j e_j^2$ is minimized), can be written as

$$\hat{y}_j = \bar{y}_j + \hat{\beta}_1 (x_{j1} - \bar{x}_1) + \ldots + \hat{\beta}_p (x_{jp} - \bar{x}_p), \qquad [2]$$

where $\bar{y}_j$ is the mean of the n observations of $y_j (j = 1, \ldots, n)$ and $\hat{y}_j$ is the predicted value of the dependent variable y_j.

Given that $\underset{\sim}{X}$ is a matrix of order $n \times p$ of X values (deviation scores $x_{ji} - \bar{x}_i$), the vector of regression weights is estimated by

$$\underset{\sim}{\hat{\beta}} = (\underset{\sim}{X}' \underset{\sim}{X})^{-1} \underset{\sim}{X}' \underset{\sim}{Y}, \qquad [3]$$

where $\underset{\sim}{Y}$ is a column vector of elements y_j and $\underset{\sim}{X}'$ is the transpose of $\underset{\sim}{X}$. The error variance σ_e^2 (where $e_j = y_j - \hat{y}_j$) is estimated by

$$s_e^{\,2} = \Sigma_j\, e_j^{\,2} \;/\; (n - 1), \tag{4}$$

and the estimates of the error variances of the $\hat{\beta}$'s are given by the respective diagonal elements of the covariance matrix

$$\text{cov}\,(\hat{\beta}) = (\underset{\sim}{X}'\underset{\sim}{X})^{-1}\, s_e^{\,2}. \tag{5}$$

The above equations assume that the independent variables are measured without error. To the extent that this is not true, the estimates of their variances will be inflated. That is, the diagonal elements of the matrix $\underset{\sim}{X}'\underset{\sim}{X}$ will be larger than they should otherwise be. In addition, since the x's are random variables chosen as plausible predictors of y, it is possible (even probable) that the estimate of error variance $s_e^{\,2}$ (Equation 4) will be an over-estimate of the true error variance of the y_j's.

The first of these effects comes into play when estimating the values of the regression coefficients in Equation 3. Because that equation involves the inverse of the matrix $\underset{\sim}{X}'\underset{\sim}{X}$, the regression coefficients are necessarily under-estimated. Both of the effects mentioned above play a part in the estimation of the covariance matrix in Equation 5. There can never be certainty that these effects will cancel out each other. Maxwell (1975) cautions:

> In summary we see that inadequate specification of y and errors of measurement in the x's lead to a situation in which the tests of significance provided for the classic model are of dubious validity in most social science applications. At best we can claim that, if e_j are calculated and found to be approximately normally distributed, a significant multiple correlation coefficient would indicate some dependence of y on a weighted sum of the x's. But the relative sizes of the regression weights would be suspect and the magnitude of the multiple correlation coefficient in particular would be the point to note. (pp. 52-53)

Both Lawley and Maxwell (1973) and Maxwell (1975) show how such errors of measurement in the x's can be handled by stating the model in factor analytic terms and proceeding from there. Essentially, the set of predictor variables is reduced to a "best" set of statistically independent variables (i.e., the factors), and then the dependent variable is predicted from these. Specifically, the analysis proceeded as follows:

The maximum likelihood estimate of the correlation matrix is given by

$$\underset{\sim}{\Sigma}^* = \underset{\sim}{\Lambda}^*\, \underset{\sim}{\Lambda}^{*\prime} + \underset{\sim}{\Psi}^*, \tag{6}$$

where

$\underset{\sim}{\Sigma}^*$ (of order $1 + p$) includes the dependent variable y together with the p independent variables,

Λ^* is a $(1 + p) \times k$ matrix of factor loadings of all the variables on the k factors, and

Ψ^* is a diagonal matrix of residual variances.

Partitioning Λ^* as

$$\Lambda^* = \begin{bmatrix} \lambda_1' \\ \Lambda \end{bmatrix} , \qquad [7]$$

where λ_1' contains the loadings of y on the factors and Λ contains the corresponding loadings of the x's, yields the regression equation

$$\hat{y} = \lambda_1' f \, . \qquad [8]$$

Estimating the factors f in this equation (see Maxwell, 1975, p. 59) yields the new regression equation

$$\hat{y} = \lambda_1' \Gamma^{-1} \Lambda' \Psi^{-1} x \, , \qquad [9]$$

where $\Gamma = \Lambda' \Psi^{-1} \Lambda$ is a diagonal matrix. In this approach, the square of the multiple correlation coefficient for the y's predicted from the x's is given by the communality of y in the maximum likelihood factor analysis.

For this study, maximum likelihood factor analyses were performed separately on the 3×3, 4×4, and 5×5 Σ^* matrices corresponding to the 2, 3, and 4 independent variable cases, respectively (the dependent variable y is always included in the Σ^* matrix). The matrices from a one-factor solution were obtained in each case and Equation 9 was calculated for predicting scores on Subtests 3, 4, and 5, respectively, from the scores on all previously administered subtests.

To examine the effect of using the corrected (versus the classical) regression equations, the subtests were administered in the same order for inter-subtest branching as they were for the classical equations. Since factor analyses cannot be performed when the number of variables is less than three, the classical regression equations were used for the prediction of Subtest 2 scores.

Since the square of the multiple correlation coefficient (R) was given by the communality of y in these analyses, the standard error of estimate (SEE) was computed using the formula

$$SEE = s_y \sqrt{1 - R^2} \qquad [10]$$

Cross-validation. Since this study was a real-data simulation of various testing strategies, the regression equations developed from students' subtest scores during any one academic quarter were used in the inter-subtest branching strategy simulated from students' item responses from that same quarter. As with any application of multiple regression techniques, the estimates of the

b-weights and the multiple correlation coefficient were likely to be inflated due to sample-specificity. To the extent that this was true, the inter-subtest branching strategy would be nonoptimal for any subsequent sample of students.

To investigate the extent to which variance in the multiple correlation coefficients and the *b*-weights affected the efficacy of the inter-subtest branching strategy employed here, a double-cross-validation design was used. Both the fall and winter quarter samples served as independent development groups, and both sets of regression equations (classical and corrected) were obtained separately for each group. Then, the equations developed from the fall data were used in the simulation with the data from both the fall and winter quarters and correspondingly for the equations developed from the winter data. The results obtained in this way allowed for a direct investigation of the extent to which the efficacy of the adaptive strategies was affected by cross-sample discrepancies in the regression equations.

Adaptive Intra-Subtest Item Selection

Brown and Weiss (1977) compared the results obtained from the entire testing strategy combining both intra-subtest item selection and inter-subtest branching with those obtained when the tests were conventionally administered. In this study the effects of the variable termination criterion in the intra-subtest item selection strategy were separated from those of the inter-subtest branching strategy, and the relative contributions of these aspects of the adaptive strategy were determined.

Consequently, a third set of testing conditions was simulated. Here, the five subtests were treated as independent sets of items. Instead of branching from one subtest to the next using the regression-based inter-subtest branching strategy, each subtest was considered to be a self-contained test. As in the conventional test, Bayesian scoring was used; and a mean of 0.0 with a variance of 1.0 was used as the initial prior $\hat{\theta}$ for each of the five subtests. Items within each subtest, however, were selected according to the intra-subtest item selection scheme described above, and the variable termination information criterion values of .01 and .05 were used. Hence, the only difference between these tests and the other sets of adaptive tests was that inter-subtest branching was not utilized here.

Dependent Variables

The important question in this study was not "Can test length be reduced by adaptive testing?" but rather "Can test length be reduced and adequate levels of measurement precision be maintained?" It would be pointless to reduce test length by 20%, 30%,or more if much of the measurement accuracy was sacrificed in the process.

Correlations of Achievement Level Estimates

One means of investigating the extent to which measurement precision was preserved or lost by the adaptive testing strategy is correlational analysis; that is, how well did the achievement estimates on the adaptive tests correlate with those on the conventional tests? For this study these correlations were obtained for each of the subtests across all testing conditions.

Information

The degree to which measurement precision is lost through test-length reduction may also be assessed by inspection of the relevant subtest information curves. The adaptive subtest information curves were obtained as follows:

A student's final $\hat{\theta}$ was obtained for any one subtest after testing terminated for that subtest. Then, the item information function (Birnbaum, 1968) was evaluated at that student's final $\hat{\theta}$ for each item that was administered adaptively. These item information values were then summed across all items administered to the student in that subtest in order to obtain the adaptive subtest information curve for that student.

The conventional subtest information curves were obtained in essentially the same way, except that the item information functions were evaluated at the $\hat{\theta}$ arising from administration of the conventional subtest, and they were summed over all the items in the subtest pool.

When a final $\hat{\theta}$ had been obtained for every student, the students were grouped into 20 nonoverlapping intervals on the basis of their $\hat{\theta}$ values from either the conventional or adaptive test. The mean subtest information value (over all students within an interval) was obtained for each of the 20 intervals separately for the conventional and adaptive tests; these mean values were then plotted at the midpoint of each interval in order to obtain the subtest information curves.

RESULTS

Preliminary Results

Item Parameters

Table 1 presents the means and standard deviations for estimates of the latent trait item parameters a, b, and c. Also included are the number and percentage of items from the final exams for which parameter estimates could be obtained. Individual item parameter estimates, by subtest, are shown in Appendix Tables A and B for the fall and winter data, respectively.

Table 1 shows that item parameters were obtained for 94% (or 46) of the 49 items available on the fall quarter final exam. This retention rate ranged from 85% of the items in the Chemistry subtest to 100% of the items in the Cell, Energy, and Reproduction subtests. The winter quarter final exam exhibited a somewhat lower retention rate, with 84% (or 31) of the 37 available items yielding parameter estimates. The Ecology subtest suffered the largest loss (75% retention), although closer inspection revealed that this was a loss of only 1 of the 4 original items; no subtest lost more than 2 items. In terms of absolute numbers of items, the winter quarter item pool was somewhat smaller than that from fall quarter: 31 parameterized items compared to 46.

The overall mean b parameter for the fall quarter item pool (-.22) was slightly lower than that for the winter quarter pool, $\bar{b}$ =.02. The mean a parameters of 1.80 and 1.81 and c parameter of .40 were essentially identical for the two pools.

Table 1
Means and Standard Deviations of Normal Ogive Item Discrimination (*a*), Difficulty (*b*), and Lower Asymptote (*c*) Parameter Estimates for the Fall and Winter Quarter Final Exams by Subtest

Quarter and Subtest	Number of Items: Available	Number of Items: Parameterized	Percent of Items Parameterized	*a* Mean	*a* *SD*	*b* Mean	*b* *SD*	*c* Mean	*c* *SD*
Fall									
Chemistry	13	11	85	1.56	.44	-.49	.78	.32	.09
Cell	9	9	100	1.84	.41	.23	1.34	.45	.09
Energy	9	9	100	2.27	.47	-.05	1.02	.42	.13
Reproduction	11	11	100	1.64	.57	-.13	.92	.40	.14
Ecology	7	6	86	1.73	.36	-.80	.67	.44	.07
Total	49	46	94	1.80	.51	-.22	.99	.40	.12
Winter									
Chemistry	10	8	80	1.77	.37	-.29	.82	.29	.07
Cell	6	6	100	1.69	.26	-.09	1.06	.38	.07
Energy	8	7	88	2.22	.49	.21	.79	.45	.14
Reproduction	9	7	78	1.53	.32	.25	1.22	.47	.11
Ecology	4	3	75	1.81	.54	.08	1.64	.51	.24
Total	37	31	84	1.81	.44	.02	1.00	.40	.14

Ordering of Subtests

The intercorrelations of Bayesian ability estimates from the five subtests in each quarter are shown in Table 2. For the data from fall quarter, these inter-subtest correlations ranged from .289 (between Ecology and Energy) to .433 (between Cell and Chemistry). The range of correlations was somewhat larger for the winter quarter data; the lowest correlation was .160 (between Cell and Ecology) and the largest correlation was .496 (between Chemistry and Energy).

Since the highest correlation was between Chemistry and Cell in the fall data and between Chemistry and Energy in the winter data, the Chemistry subtest was designated to be administered first in each case; the Cell subtest was administered second for the fall quarter equations and the Energy subtest was administered second for the winter quarter equations.

Table 2
Intercorrelations of Bayesian Ability Estimates on the Five Subtests of the Fall (Below Diagonal) and Winter (Above Diagonal) Quarter Final Exams

Subtest	Chemistry	Cell	Energy	Reproduction	Ecology
Chemistry		.451	.496	.379	.228
Cell	.433		.456	.301	.160
Energy	.412	.370		.347	.189
Reproduction	.388	.344	.321		.221
Ecology	.387	.302	.289	.302	

For the fall quarter data, multiple regression equations were obtained using the Chemistry and Cell subtests as independent variables and each of the other subtests, in turn, as the dependent variable. Because the Energy subtest had the highest multiple correlation with these first two subtests, it was chosen as the third subtest to be administered. This procedure was repeated to select the fourth and fifth subtests for administration. The same process was carried out using the winter quarter data.

Appendix Table C shows the intermediate classical regression equations used to choose the order of administration of the subtests for both fall and winter quarters. For the fall equations the subtests were ordered in the following sequence: Chemistry, Cell, Energy, Reproduction, and Ecology. For the winter equations the order was Chemistry, Energy, Cell, Reproduction, and Ecology.

Table 3 shows the classical (or uncorrected) regression coefficients, multiple correlation coefficients, and standard errors of estimate for the sets of regression equations from both the fall and winter data. These equations were those used for inter-subtest branching.

Table 3
Regression Coefficients, Multiple Correlation Coefficients (R), and Standard Errors of Estimate (SEE) for the Classical Regression Equations from the Fall and Winter Quarter Final Exams

Quarter and Criterion Subtest	Regression Coefficients for Scores on Previously Administered Subtests: Chemistry	Cell	Energy	Reproduction	Regression Constant	R	SEE
Fall							
Cell	.400				.137	.433	.680
Energy	.328	.272			-.009	.464	.768
Reproduction	.240	.190	.140		.204	.455	.707
Ecology	.221	.110	.089	.128	-.029	.446	.665
Winter							
Energy	.461				.056	.496	.637
Cell	.276		.305		-.144	.525	.620
Reproduction	.258	.129	.203		.134	.432	.761
Ecology	.102	.026	.052	.103	.112	.278	.595

Corrected Equations

The corrected regression coefficients, multiple correlation coefficients, and standard errors of estimate from the fall and winter final exams are given in Table 4. The factor loadings and estimates of communalities used to compute these equations are given in Appendix Table D. It should be noted that the factor analytic techniques could not be applied, of course, unless there were at least three variables in the regression equation. Hence, for the cases in which there were only two variables, e.g., one predictor subtest and one criterion subtest, the classical (or uncorrected) regression equation was used. Therefore, the first and fifth lines in Table 4 match exactly the first and fifth lines, respectively, of Table 3.

Table 4
Regression Coefficients, Multiple Correlation Coefficients (*R*), and Standard Errors of Estimate (*SEE*) for the Corrected Regression Equations from the Fall and Winter Quarter Final Exams

Quarter and Criterion Subtest	Regression Coefficients for Scores on Previously Administered Subtests: Chemistry	Cell	Energy	Reproduction	Regression Constant	*R*	*SEE*
Fall							
Cell	.400				.137	.433	.680
Energy	.538	.446			-.008	.594	.698
Reproduction	.345	.279	.216		.206	.552	.662
Ecology	.266	.195	.152	.152	-.024	.523	.633
Winter							
Energy	.461				.056	.496	.637
Cell	.416		.461		-.132	.644	.557
Reproduction	.296	.230	.295		.153	.504	.729
Ecology	.119	.088	.113	.051	.127	.303	.590

Comparison of the entries in Table 3 with those in Table 4 reveals that the Lawley-Maxwell method of correction for multiple regression equations did indeed increase the sizes of both the multiple correlation coefficient and the regression coefficients. Inspection of the fall quarter data, for example, shows that the corrected multiple correlation coefficients increased from R = .464, .455, and .446 to R = .594, .552, and .523, respectively; there were corresponding decreases in the sizes of the standard errors of estimate. The b-weights also increased in size, with the largest increases occurring in those equations with the fewest independent variables. For example, when the Energy subtest was the criterion, the regresssion coefficients for the Chemistry and Cell subtests increased from b = .328 and .272 to b = .538 and .446, respectively.

A similar effect was observed with the winter quarter data. Here, the corrected multiple correlation coefficients increased from R = .525, .432, and .278 to R = .644, .504, and .303, respectively; again, there were corresponding decreases in the sizes of the standard errors of estimate. All but one of the b-weights increased in size; the b-weight for the Reproduction subtest in the final equation decreased from .103 to .051.

Test Length

Mean Test Length

Table 5 presents the mean numbers of items administered in each of the five subtests and in the total test for the conventional test and for the adaptive test using adaptive intra-subtest item selection but no inter-subtest branching.

Conventional test. During the actual final exam in each quarter, students were free to omit any 10 (of 110) items of their choice. To the extent that students omitted some of the items with ICC parameters that were selected for inclusion in these simulation item pools (i.e., from the five content areas--

Chemistry, Cell, Energy, Reproduction, and Ecology), the number of items for which student responses were available varied across students. Thus, in these five content areas, students answered from 37 to 46 of the parameterized items in fall and 23 to 31 items in winter. Consequently, the conventionally administered test was, on the average, 43 items long for the fall quarter data and 28.55 items long for the winter data.

Table 5
Number of Items Administered in the Five Subtests of the Fall and Winter Quarter Final Exams with No Inter-Subtest Branching

Subtest and Data	Conventional Test				Adaptive Intra-Subtest Item Selection: Termination Criterion .01				.05			
	Mean	*SD*	Range Min	Range Max	Mean	*SD*	Range Min	Range Max	Mean	*SD*	Range Min	Range Max
Chemistry												
Fall	10.21	.91	6	11	9.13	1.41	5	11	8.09	1.59	4	11
Winter	7.48	.72	4	8	6.59	1.16	3	8	5.85	1.16	2	8
Cell												
Fall	8.50	.71	5	9	6.93	.89	3	8	5.68	1.10	3	7
Winter	5.64	.60	3	6	4.73	.85	2	6	4.26	.71	2	5
Energy												
Fall	8.09	.95	4	9	5.96	1.03	3	9	5.15	.88	2	8
Winter	5.91	1.01	2	7	4.67	.95	2	7	4.30	1.03	2	7
Reproduction												
Fall	10.46	.84	7	11	8.78	1.08	4	11	7.67	1.33	4	10
Winter	6.69	.56	3	7	4.93	1.09	1	7	4.04	.80	1	5
Ecology												
Fall	5.73	.50	3	6	5.24	.74	2	6	4.07	1.20	2	6
Winter	2.82	.38	2	3	1.95	.21	1	2	1.07	.26	1	2
Total Test												
Fall	43.00	1.77	37	46	36.04	2.46	28	42	30.67	3.17	22	41
Winter	28.55	1.60	23	31	22.87	2.47	14	29	19.52	2.12	12	26

The discrepancy between the two quarters in the numbers of items available in the conventional test for this study was fairly evenly distributed across all five subtests, so that the relative size of each subtest remained about the same (see Table 1). That is, Chemistry and Reproduction were the longest subtests, and Ecology was consistently the shortest.

Adaptive intra-subtest item selection. In these sets of tests, the intra-subtest item selection strategy was employed with a variable termination criterion, but no inter-subtest branching scheme was used. That is, a prior $\hat{\theta}$ of 0.0 with an estimated variance of 1.0 was used as an entry point in each of the five subtests. Table 5 shows data on test lengths obtained for each subtest under the two termination criteria used in this study (item information of .01 and .05). During the fall quarter the length of the total test battery averaged 36.04 items under the more stringent termination criterion, .01, and 30.67 items under the termination criterion of .05. For winter quarter these figures were 22.87 and 19.52, respectively.

In all cases the maximum number of items administered under this adaptive strategy represented some reduction in total test battery length. For the fall data no student answered more than 42 items under the .01 termination criterion; and the shortest adaptive test was only 28 items long. For the .05 criterion the longest test was 41 items; the shortest was 22. For the winter quarter data these figures were 29 and 14 for the .01 termination criterion and 26 and 12 for the .05 criterion.

Inter-subtest branching. When the inter-subtest branching strategy was employed in addition to the adaptive intra-subtest item selection strategy and variable termination criterion, test length was reduced even further. Tables 6 and 7 show the mean test lengths under these conditions, when both the classical and corrected regression equations were developed on the data from the fall and winter quarters, respectively. Data for the Chemistry subtest (the first subtest administered) are the same in the two tables because the initial θ was assumed to be 0.0 with a variance of 1.0 for all students and was constant for the first subtest, regardless of branching strategy used (e.g., no branching versus inter-subtest branching).

For both the .01 and .05 termination criterion, the addition of the inter-subtest branching strategy generally resulted in shorter tests; the exception was the Ecology subtest with a .05 termination criterion under all testing conditions. However, in comparison to the results from use of intra-subtest branching only (see Table 5), this reduction was slight--never more than one item for the total test. The data also show that the branching strategy utilizing the corrected regression equations resulted in tests that were shorter than when the classical regression equations were used, although the difference was very slight. For example, under the .01 termination criterion, the classical fall quarter regression equations resulted in a total test battery length of 35.61 items for the fall data and 35.15 items when the corrected regression equations were used (Table 6). When the .05 termination criterion was used, the classical fall quarter equations resulted in a mean test battery length of 30.33 items versus 30.10 items for the corrected equations. There was a tendency for the corrected equations to result in higher standard deviations of numbers of items administered in the total test than did the classical equations; this was due to the tendency toward shorter minimum total test lengths. Similar results were observed when the winter quarter equations were used (see Table 7).

Cross-validation. There was very little difference between total test lengths in the development groups and in cross-validation; the differences which were found were usually in the direction of shorter tests when the regression equations were cross-validated on data from the other quarter. For example, when the classical regression equations developed on winter quarter data were applied to that same data, mean test length was 22.64 and 19.90 for termination criteria of .01 and .05, respectively (see Table 7). When the cross-validated classical fall quarter equations were applied to that winter data (Table 6), however, the means were 22.58 and 19.68, respectively. The results for the classical regression equations applied to the fall quarter data were mixed. When the results from the sets of corrected equations were compared, they favored the cross-validated condition whenever a difference was found.

Table 6
Number of Items Administered in the Five Subtests of the Fall and Winter Quarter Final Exams
for the Adaptive Test with Intra-Subtest Item Selection and Inter-Subtest Branching
Using Classical and Corrected Regression Equations from Fall Data

Subtest	Classical Equations: Termination Criterion								Corrected Equations: Termination Criterion							
	.01				.05				.01				.05			
			Range				Range				Range				Range	
and Data	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
Chemistry																
Fall	9.13	1.41	5	11	8.09	1.59	4	11	9.13	1.41	5	11	8.09	1.59	4	11
Winter	6.59	1.16	3	8	5.85	1.16	2	8	6.59	1.16	3	8	5.85	1.16	2	8
Cell																
Fall	6.78	.84	4	8	5.54	1.34	2	8	6.78	.84	4	8	5.54	1.34	2	8
Winter	4.64	.79	2	6	4.07	.89	1	5	4.64	.79	2	6	4.07	.89	1	5
Energy																
Fall	5.84	1.20	2	9	4.91	1.11	2	8	5.66	1.33	2	9	4.77	1.27	1	8
Winter	4.57	1.21	1	7	4.14	1.30	1	7	4.39	1.37	1	7	3.92	1.48	0	7
Reproduction																
Fall	8.67	1.17	5	11	7.58	1.41	3	10	8.51	1.34	4	11	7.50	1.55	2	10
Winter	4.92	.97	1	7	4.13	.88	1	6	4.83	1.06	1	7	4.06	.93	1	7
Ecology																
Fall	5.19	.79	2	6	4.22	1.25	1	6	5.06	.94	2	6	4.20	1.28	1	6
Winter	1.86	.35	0	2	1.50	.51	0	2	1.78	.42	0	2	1.50	.51	0	2
Total Test																
Fall	35.61	2.94	24	43	30.33	3.81	18	41	35.15	3.44	22	43	30.10	4.16	15	41
Winter	22.58	2.87	13	29	19.68	2.64	11	26	22.24	3.12	12	29	19.40	2.86	10	26

Note. Winter data is cross-validation.

Table 7
Number of Items Administered in the Five Subtests of the Fall and Winter Quarter Final Exams for the Adaptive Test with Intra-Subtest Item Selection and Inter-Subtest Branching Using Classical and Corrected Regression Equations from Winter Data

Subtest and Data	Classical Equations: Termination Criterion								Corrected Equations: Termination Criterion							
	.01				.05				.01				.05			
			Range				Range				Range				Range	
	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max
Chemistry																
Winter	6.59	1.16	3	8	5.85	1.16	2	8	6.59	1.16	3	8	5.85	1.16	2	8
Fall	9.13	1.41	5	11	8.09	1.59	4	11	9.13	1.41	5	11	8.09	1.59	4	11
Energy																
Winter	4.69	1.16	1	7	4.28	1.19	1	7	4.69	1.16	1	7	4.28	1.19	1	7
Fall	5.92	1.17	2	9	5.05	1.02	2	8	5.92	1.17	2	9	5.05	1.02	2	8
Cell																
Winter	4.54	.80	2	6	4.02	.84	2	5	4.50	.82	2	6	3.93	.93	1	5
Fall	6.62	1.00	2	8	5.59	1.34	2	8	6.33	1.24	2	8	5.29	1.60	1	8
Reproduction																
Winter	4.86	1.03	1	7	4.09	.88	1	6	4.79	1.07	1	7	4.01	.90	1	7
Fall	8.66	1.20	4	11	7.59	1.43	2	10	8.53	1.39	4	11	7.51	1.58	2	10
Ecology																
Winter	1.95	.21	1	2	1.68	.47	0	2	1.87	.34	0	2	1.34	.48	0	2
Fall	5.23	.76	2	6	4.41	1.09	2	6	5.24	.74	2	6	4.15	1.29	1	6
Total Test																
Winter	22.64	2.87	13	29	19.90	2.68	11	26	22.44	2.98	13	29	19.40	2.54	10	25
Fall	35.56	2.95	22	43	30.73	3.79	17	40	35.14	3.45	21	43	30.09	4.16	16	40

Note. The results from the winter data are presented before those from fall in this table because the winter data represent the development group, and the fall data the cross-validation group.

Percent Reduction in Test Length

Table 8 summarizes the percent reduction in the mean number of items administered in each subtest and in the total test under the various testing conditions.

Adaptive intra-subtest item selection. The first column of data in Table 8 represents the reduction in mean test length that was observed when only the adaptive intra-subtest item selection strategy with a variable termination criterion was compared to a conventionally administered test. In both these adaptive and conventional tests, each subtest was treated as a separate unit with no inter-subtest branching between tests. For the fall quarter data, use of the adaptive testing strategy decreased total test length by 16.19% under the .01 termination criterion and decreased it by as much as 28.67% when the .05 criterion was used. When this strategy was used on the winter quarter data, the respective reductions were 19.89% and 31.63% in total test length.

The largest reduction in subtest length using a termination criterion of .01 occurred for the fifth subtest, Ecology, and amounted to a total decrease of almost 31% of the items. This effect, however, was limited to the winter data, as the Ecology subtest for the fall data exhibited a reduction of less than 9%. On the average, the Chemistry subtest (the first subtest administered) showed the smallest decrease in number of items administered--about 10 to 12%. The same pattern was observed among the subtests when a termination criterion of .05 was used. That is, the largest reduction in subtest length was observed for the Ecology subtest for the winter data (62.06%); and the smallest reduction, on the Chemistry subtest for the fall data (20.76%).

Inter-subtest branching. The remaining columns of Table 8 show the results obtained when the inter-subtest branching scheme was coupled with the adaptive intra-subtest item selection strategy and then compared to a conventionally administered test. The reductions in total test length were slightly greater than those obtained when the inter-subtest branching strategy was not utilized.

For example, when the fall quarter equations were applied to the fall quarter data, the reduction in average test length for the total test increased from 16.19% to 17.19% for the classical equations and 18.26% for the corrected equations under the .01 termination criterion. These figures were 28.67%, 29.47%, and 30.00%, respectively, for the .05 termination criterion. Use of the corrected regression equations generally resulted in somewhat shorter total test lengths than did use of the classical equations, although the difference was slight.

When the winter quarter equations were applied to the winter quarter data, total test length was reduced from 19.89% to 20.70% for the classical equations and 21.40% for the corrected equations under the .01 termination criterion. These figures were 31.63%, 30.30%, and 32.05%, respectively, for the .05 termination criterion. Use of the classical equations actually resulted in tests which were slightly longer under the .05 criterion than when no inter-subtest branching strategy was used. Use of the corrected equations, however, resulted in shorter tests, as expected.

In general (across both sets of data), additional reduction in test length was less than three percentage points, and most often one percentage point or

Table 8

Percent Reduction from the Conventional Test in Mean Number of Items Administered in the Five Subtests of the Fall and Winter Quarter Final Exams With and Without Inter-Subtest Branching Using Classical and Corrected Regression Equations Developed from Each Quarter

Subtest and Data	Adaptive Intra Subtest Item Selection: Termination Criterion		Percent Mean Reduction[a] Due to Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching							
			Classical Equations				Corrected Equations			
			Fall: Termination Criterion		Winter: Termination Criterion		Fall: Termination Criterion		Winter: Termination Criterion	
	.01	.05	.01	.05	.01	.05	.01	.05	.01	.05
Chemistry										
Fall	10.58	20.76	10.58	20.76	10.58	20.76	10.58	20.76	10.58	20.76
Winter	11.90	21.79	11.90	21.79	11.90	21.79	11.90	21.79	11.90	21.79
Cell										
Fall	18.47	33.18	20.24	34.82	22.12	34.24	20.24	34.82	25.53	37.76
Winter	16.13	24.47	17.73	27.84	19.50	28.72	17.73	27.84	20.21	30.32
Energy										
Fall	26.33	36.34	27.81	39.31	26.82	37.58	30.04	41.04	26.82	37.58
Winter	20.98	27.24	22.67	29.95	20.64	27.58	25.72	33.67	20.64	27.58
Reproduction										
Fall	16.06	26.67	17.11	27.53	17.21	27.44	18.64	28.30	18.45	28.20
Winter	26.31	39.61	26.46	38.27	27.35	38.86	27.80	39.31	28.40	40.06
Ecology										
Fall	8.55	28.97	9.42	26.35	8.73	23.04	11.69	26.70	8.55	27.57
Winter	30.85	62.06	34.04	46.81	30.85	40.43	36.88	46.81	33.69	52.48
Total Test										
Fall	16.19	28.67	17.19	29.47	17.30	28.53	18.26	30.00	18.28	30.02
Winter	19.89	31.63	20.91	31.07	20.70	30.30	22.10	32.05	21.40	32.05

[a]Computed by the formula: 100-[(Mean number of items in appropriate adaptive test/mean number of items in conventional test) × 100].

less. Use of the corrected equations resulted in shorter tests in all cases in comparison with use of adaptive intra-subtest item selection alone. The Energy subtest showed the largest decreases in test length across testing conditions (with the exception of the Ecology subtest administered during winter quarter, which showed the greatest reduction in test length). This was followed closely by the Cell, Reproduction, and Chemistry subtests, respectively. During fall quarter the decrease in the length of the Ecology subtest was the smallest.

Cross-validation. When the fall quarter equations were applied to the data from winter quarter in the cross-validation condition, test-length reduction increased from 19.89% with no inter-subtest branching to 20.91% for the classical equations and 22.10% for the corrected equations, under the .01 termination criterion. For the termination criterion of .05,these figures were 31.63% with no inter-subtest branching and 31.07% and 32.05% for the two inter-subtest branching conditions with .01 and .05 termination, respectively. With the winter data there was a slight increase in test length on cross-validation from 28.67% without inter-subtest branching to 30.30% for the classical equations and .05 termination criterion.

For the double-cross-validation condition, when the winter quarter equations were applied to the fall quarter data, reductions in test length were again observed. For the .01 termination criterion, test length decreased from 16.19% without inter-subtest branching to 17.30% for the classical equations and 18.28% for the corrected equations. These figures were 28.67%, 28.53%, and 30.02%, respectively, for the .05 termination criterion. (Only with the .01 termination criterion were the tests with the cross-validated equations consistently shorter than the tests with the original (development group) equations. At the .05 termination level the results from the classical and corrected equations were mixed.

In summary, for the .01 termination criterion the reduction in total test length for the data from each of the quarters was nearly always greater when the regression equations were cross-validated. The results from using the .05 criterion were mixed. As was observed with the two development groups, use of the corrected equations resulted in shorter mean test lengths under cross-validation than did use of the cross-validated classical equations. In all cases, however, observed differences in test length reduction were slight.

Minimum and maximum reductions in test length. The data in Table 8 reflect only the reductions in average test lengths. Table 9 presents the minimum and maximum reductions from the conventional test length that were observed for any one student when the inter-subtest branching strategy was used. Inspection of this table reveals that for each testing condition (except for the corrected fall equations applied to the winter data with .01 termination criterion), total test length was reduced for all students by at least 2.5%. The largest reduction in total test length was that observed for the fall data using corrected fall equations and a termination criterion of .05, where the reduction was 67.4%.

For each subtest separately the minimum reduction in subtest length (for all tests but one) was 0%; that is, there was at least one student who was administered all the available items in a subtest regardless of testing condition. However, there also were students whose subtests were reduced in length by more

Table 9

Minimum and Maximum Percent Reduction from the Conventional Test Length Observed for Any One Student When the Adaptive Inter-Subtest Branching Strategy Was Used in the Five Subtests of the Fall and Winter Quarter Final Exams

	Classical Equations								Corrected Equations							
	Fall: Termination Criterion				Winter: Termination Criterion				Fall: Termination Criterion				Winter: Termination Criterion			
Subtest	.01		.05		.01		.05		.01		.05		.01		.05	
and Data	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Chemistry																
Fall	0.0	37.5	0.0	50.0	0.0	37.5	0.0	50.0	0.0	37.5	0.0	50.0	0.0	37.5	0.0	50.0
Winter	0.0	42.9	0.0	57.1	0.0	42.9	0.0	57.1	0.0	42.9	0.0	57.1	0.0	42.9	0.0	57.1
Cell																
Fall	0.0	55.6	0.0	75.0	0.0	66.7	0.0	77.8	0.0	55.6	0.0	75.0	0.0	77.8	0.0	88.9
Winter	0.0	50.0	0.0	75.0	0.0	50.0	0.0	66.7	0.0	50.0	0.0	75.0	0.0	66.7	0.0	83.3
Energy																
Fall	0.0	77.8	0.0	77.8	0.0	77.8	0.0	77.8	0.0	77.8	0.0	88.9	0.0	77.8	0.0	77.8
Winter	0.0	71.4	0.0	85.7	0.0	66.7	0.0	85.7	0.0	85.7	0.0	100.0	0.0	60.0	0.0	85.7
Reproduction																
Fall	0.0	54.5	0.0	72.7	0.0	54.5	0.0	81.8	0.0	54.5	0.0	81.8	0.0	54.5	0.0	81.8
Winter	0.0	80.0	0.0	80.0	0.0	80.0	14.3	80.0	0.0	80.0	0.0	80.0	0.0	80.0	0.0	80.0
Ecology																
Fall	0.0	50.0	0.0	75.0	0.0	40.0	0.0	60.0	0.0	60.0	0.0	75.0	0.0	40.0	0.0	75.0
Winter	0.0	100.0	0.0	100.0	0.0	50.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
Total Test																
Fall	2.5	45.7	9.8	60.9	2.5	52.2	7.5	63.0	2.5	47.8	5.0	67.4	2.5	54.3	7.5	65.2
Winter	3.3	50.0	12.0	58.6	3.3	50.0	12.0	58.6	0.0	53.8	13.3	65.5	3.3	50.0	14.3	60.7

than 75%. In fact, there were some subtests (specifically, Ecology) that students "skipped" altogether, as evidenced by the 100% maximum reduction figures for most of the winter data.

It would be expected that as the tests continued and more information was available with which to predict scores on subsequent subtests, these predicted scores--hence, entry points into the subtest--would become more accurate. This should be reflected in more stable ability estimates and therefore shorter subsequent subtests. Indeed, there is a trend in the data of Table 9 for increasingly larger reductions in test length for the tests administered later in the inter-subtest branching.

Correlations of Achievement Level Estimates

Table 10 presents the values of the correlation coefficients (r) between the Bayesian $\hat{\theta}$ values from the conventional tests and the adaptive tests, under all testing conditions. Generally, these correlations were fairly homogeneous; more than half of them were greater than .90, while less than 10% of them were below .80.

Adaptive Intra-Subtest Item Selection

With no inter-subtest branching, the largest correlations were those observed for the Cell subtest with variable termination .01--for both sets of data, r = .998; and for the Ecology subtest under the same conditions for winter data, r = .995. The smallest correlation was observed for the Ecology subtest with a termination criterion of .05; here, the winter data correlation was r = .527. This appears rather low, but the average length of this adapted subtest was only 1.07 items (see Table 5).

Inter-Subtest Branching

Classical equations. When the classical fall quarter equations were applied to the data collected from that same quarter, the range of correlations was fairly small. These correlations ranged from .846 (for the Energy subtest) to .979 (for the Cell subtest) with the .01 termination criterion. For the termination criterion of .05, these correlations were .795 (for Energy) and .890 (for both Reproduction and Ecology).

When the winter quarter equations were applied to the winter data, the correlations varied even less. For the .01 termination criterion the range was from .921(for Reproduction) to .983 (for Chemistry). For the .05 criterion the range was from .876 (for Reproduction) to .962 (for Chemistry).

In general, the addition of an inter-subtest branching strategy to adaptive intra-subtest item selection reduced the correlations between conventional and adaptive subtest scores by a small amount (less than .021 for the fall data and less than .040 for the winter data). The single exception to this was for the winter administration of the Ecology subtest (termination criterion of .05), where inter-subtest branching increased the correlation from .527 to .886. These reductions in the correlations can be accounted for by the decreases in number of items with which θ was estimated; the inter-subtest branching strategy typically reduced test length over that obtained with intra-subtest

Table 10

Correlations of Bayesian Achievement Level Estimates for the Adaptive and Conventional Testing Strategies for Each Subtest of the Fall and Winter Quarter Final Exams

Subtest and Data	Adaptive Intra-Subtest Item Selection: Termination Criterion		Adaptive Inter-Subtest Item Selection with Intra-Subtest Branching							
			Classical Equations				Corrected Equations			
			Fall: Termination Criterion		Winter: Termination Criterion		Fall: Termination Criterion		Winter: Termination Criterion	
	.01	.05	.01	.05	.01	.05	.01	.05	.01	.05
Chemistry										
Fall	.941	.887	.941	.887	.941	.887	.941	.887	.941	.887
Winter	.983	.962	.983	.962	.983	.962	.983	.962	.983	.962
Cell										
Fall	.998	.873	.979	.858	.966	.883	.979	.858	.889	.830
Winter	.998	.964	.972	.924	.960	.935	.972	.924	.918	.879
Energy										
Fall	.852	.808	.846	.795	.842	.792	.818	.770	.842	.792
Winter	.989	.943	.972	.914	.967	.923	.926	.882	.967	.923
Reproduction										
Fall	.942	.909	.924	.890	.926	.891	.904	.871	.914	.873
Winter	.941	.898	.926	.862	.921	.876	.895	.833	.889	.836
Ecology										
Fall	.940	.871	.919	.890	.936	.912	.889	.863	.928	.882
Winter	.995	.527	.887	.759	.958	.886	.768	.671	.917	.715

item selection alone. This effect can also be seen by comparing the results from the two termination criteria; the correlations were typically lower for the .05 criterion, which generally yielded shorter tests.

Corrected equations. The pattern of correlations observed for the tests using the corrected regression equations paralleled that observed for the classical equations. That is, the range of correlations was fairly small for both the fall and winter quarter data sets, ranging from .818 to .979 under the .01 termination criterion for the fall quarter Energy and Cell subtests, respectively, and from .770 to .887 under the .05 termination criterion for the fall quarter Energy and Chemistry subtests, respectively.

For the winter quarter equations applied to the winter data, the range of conventional-adaptive score correlations was from .889 (for Reproduction) to .983 (for Chemistry) under the .01 criterion and from .715 (for Ecology) to .962 (for Chemistry) under the .05 criterion. In all cases, the correlations obtained using the classical equations were at least as large as, and usually larger than, those obtained using the corrected regression equations.

Cross-Validation

Under the cross-validation conditions (when fall equations were applied to winter data, and vice versa), there was no systematic tendency for the correlations to be either higher or lower than those obtained in the development groups. For the sets of classical and corrected equations alike, cross-validation yielded higher correlations about half the time and lower correlations the other half. Thus, there appears to be no net decrement or increment in the accuracy of measurement when regression equations that were developed on one group were applied in the inter-subtest branching strategy to data for a different group.

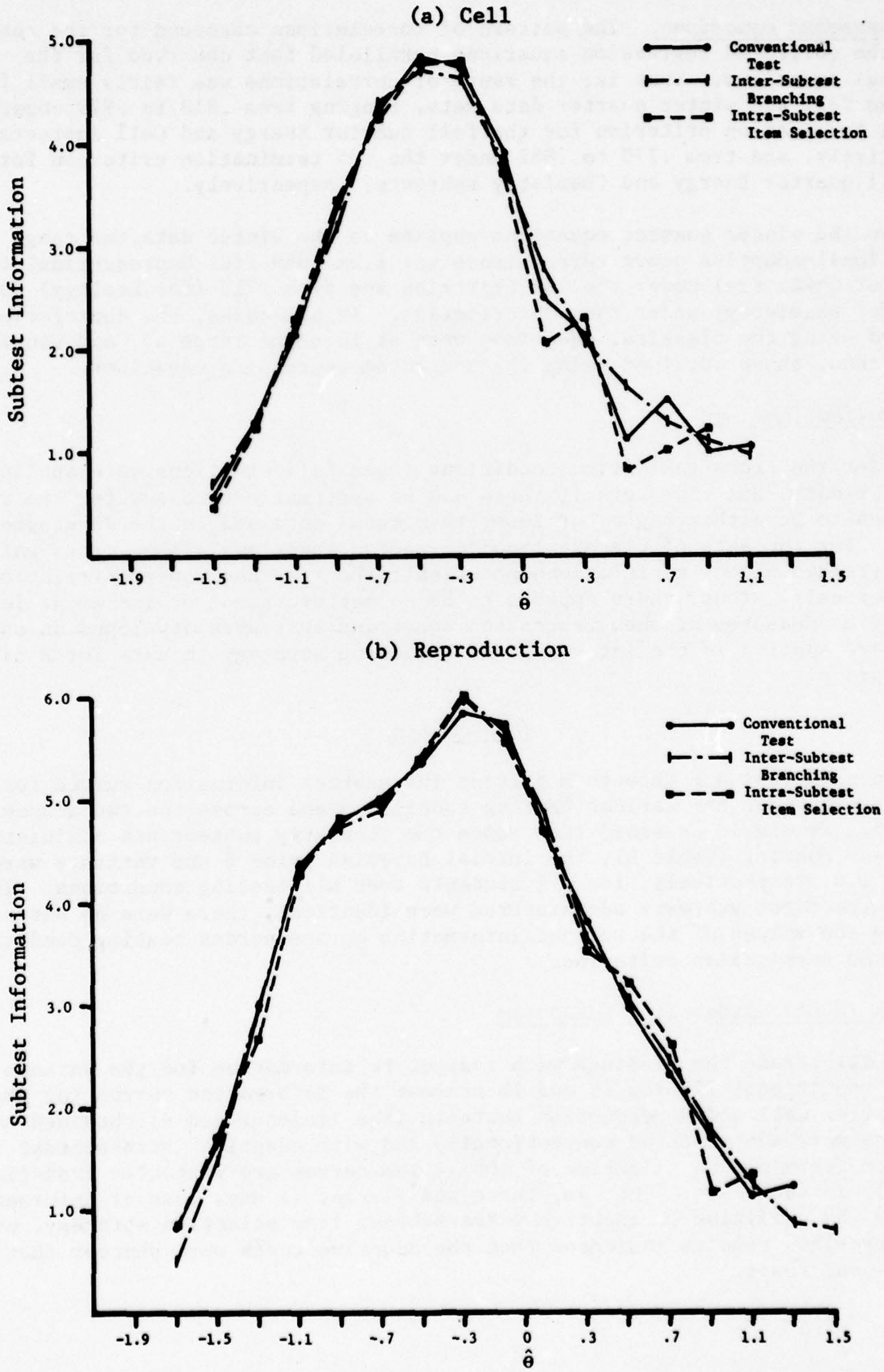
Information

Appendix Tables E through M present the subtest information curves for each subtest under the various testing conditions and across the two academic quarters. It should be noted that since the Chemistry subtest was administered first each quarter (Table E), the initial Bayesian prior $\hat{\theta}$ and variance were 0.0 and 1.0, respectively, for all students over all testing conditions. Thus, because the first subtests administered were identical, there were no differences in the values of the subtest information curves across testing conditions within one termination criterion.

Adaptive Intra-Subtest Item Selection

To illustrate the findings with respect to information for the various testing conditions, Figures 1a and 1b present the information curves for the fall quarter Cell and Reproduction subtests (see Tables F and H) obtained when the tests were administered conventionally and with adaptive intra-subtest item selection (termination criterion of .05). The curves are virtually indistinguishable in each case. That is, there was little, if any, loss of information incurred by utilizing an adaptive intra-subtest item selection strategy, even though previous results indicated that the adaptive tests were shorter than the conventional tests.

Figure 1
Subtest Information Curves for the Fall Quarter Cell and Reproduction Subtests Administered Conventionally, with Intra-Subtest Item Selection and Inter-Subtest Branching



For the Cell subtest (Figure 1a) there was a slightly larger separation between the curves above the point at which the curves were peaked, with the adaptive test slightly lower than the conventional test; this pattern is not evident in Figure 1b. The differences observed in these figures were even smaller when the more stringent termination criterion (.01) was used (see Tables F and H).

Inter-Subtest Branching

Classical equations. Also included in Figures 1a and 1b are the information curves obtained using an inter-subtest branching strategy with the classical fall equations and a termination criterion of .05. There is, again, minimal separation among the curves, particularly for the Reproduction subtest. As before, the curves begin to differ for the Cell subtest in the upper tail, with the inter-subtest branching strategy resulting in higher information values than the other two strategies.

Corrected equations. For both the fall and winter data the information curves obtained using the corrected equations were nearly always lower than the curves obtained with the classical equations. While this difference was small, it was consistent across all five subtests for each quarter (see Tables F through M).

Cross-Validation

When the classical regression equations were used on the fall data, subtest information was slightly, though systematically, higher under cross-validation than for the development groups. That is, applying winter quarter equations to fall quarter data yielded higher levels of information, on the average, than did applying the fall quarter equations to the fall data. This effect was consistent across all five subtests for the fall data. For the winter data, the results were mixed.

When the corrected regression equations were used in cross-validation, the results were mixed for both sets of data. For about half of the subtests, there was a small increase in information, and for the rest of the subtests there was a small decrease in information; thus, there was no net change in information on cross-validating with the corrected equations. In all cases, differences between mean information levels across the various testing conditions were slight.

DISCUSSION

This paper has endeavored to replicate previously reported findings (Brown & Weiss, 1977) that a combination of adaptive intra-subtest item selection and inter-subtest branching strategies could significantly reduce the length of an achievement test battery, with a corresponding minimal loss in psychometric test information. The present study applied this adaptive testing strategy to the responses from a conventionally administered classroom exam and separated out the effects of adaptive intra-subtest item selection and inter-subtest branching on test length and test information. In addition, this paper investigated the effects of using an adaptive testing strategy developed from one set of data on a different data set using a double-cross-validation design.

Adaptive Intra-Subtest Item Selection

The adaptive intra-subtest item selection strategy used in this study was identical to that utilized by Brown and Weiss (1977); that is, items were selected on the basis of the amount of psychometric information available at the current level of $\hat{\theta}$. Although the θ estimates would most appropriately be obtained using a maximum likelihood scoring strategy, this strategy utilized a Bayesian scoring approach. Maximum likelihood scoring requires the availability of at least one correct and one incorrect response before a $\hat{\theta}$ can be generated, and the Bayesian routine has no such requirement. With the possibility of a very small number of items being administered in any one subtest, and the necessity of scoring responses after each item, a maximum likelihood method would be nonoptimal for this testing strategy.

Kingsbury and Weiss (1979) illustrated the extent to which these two scoring methods, when applied to the same set of data, yield scores that are numerically discrepant. The issue of the appropriate choice of scoring strategy pervades implementations of ICC test theory in general and hence is not confined to this particular implementation of an adaptive testing strategy. Nevertheless, it is not known to what extent the results reported here would have changed had the scoring routine been different.

As Table 8 indicates, most of the reduction in test length was due to the variable termination criterion of the intra-subtest item selection strategy. Although test length decreased, the conventional-adaptive test score correlations remained high (often close to 1.00; see Table 10), and there was virtually no loss in the amount of psychometric information available for each subtest. It is clear from these data that subtest length can be reduced from 16% to 32%, with minimal loss in measurement accuracy and precision, simply by omitting those items which add little information to the measurement process.

Inter-Subtest Branching

Utilization of prior information in the estimation of achievement levels further decreased test length by less than 5%, and most often by 1% or less. Although this additional effect was small, it appeared to be fairly consistent across types of regression equations and sets of data; that is, in nearly all cases the addition of the inter-subtest branching strategy resulted in some increased reduction in test length.

Brown and Weiss (1977) reported an average decrease in the length of their test battery of approximately 50%. The largest decrease in the present study was approximately 32%, and that was obtained with a termination criterion (.05) less stringent than the one used in the former study. Part of this discrepancy may lie in the number of items available in each subtest and in the total test. In the earlier study, each subtest was between 12 and 24 items long, and the entire battery contained 201 items. The biology tests used in the present study, however, were much shorter, with a total of only 49 items during fall quarter and 37 items during winter quarter; the lengths of the subtests were correspondingly small. It seems reasonable that the longer subtests in the Brown and Weiss study contained much redundant information and that this would naturally lead to larger reductions in test length.

It would be interesting to compare between studies the extent to which inter-subtest branching reduced test length over and above that obtained by

intra-subtest item selection alone. Unfortunately, Brown and Weiss (1977) did not present that information. More research is needed to determine how representative the present figure of 5% is across different data sets.

When Brown and Weiss computed the conventional-adaptive test score correlations, they found that most of them were above .90, with only 1 of their 12 correlations dropping below that value. There was a greater range for these correlation coefficients in the present study, although here, too, most of them were greater than .90. The lengths of the subtests varied across the two studies, so direct comparison of the correlation coefficients is difficult. The correlations obtained in the previous study may have been larger than in the present one, but the adapted subtests were typically longer as well. This is very likely due to the part-whole correlations which would necessarily increase with the size of the smaller (adapted) part.

Both of these studies concluded that there was minimal loss in the amount of psychometric information observed in each subtest. Brown and Weiss utilized termination criterion of .01 and .001; it is interesting to note that the same conclusion was reached in the present study, which utilized termination criteria that were much less stringent (.05 and .01).

Corrected Regression Equations

The use of Lawley and Maxwell's (1973) correction for error in the independent variables in multiple regression increased the value of the multiple correlation coefficient and the regression coefficients (see Tables 3 and 4). The important issue here, however, was whether this correction affected test length, and accuracy and precision of measurement. On the average, use of the corrected equations decreased test length slightly more than did use of the classical equations. It was impossible to detect any large difference in this data set, however, because there was such a small additional reduction in test length attributable to any kind of inter-subtest branching.

The average correlations between the adaptive and conventional achievement estimates were lower when the corrected equations were used than when the classical equations were used. Although this is puzzling in light of the data in Tables 3 and 4, it becomes less so considering the fact that the corrected equations typically resulted in shorter test lengths. At least part of the discrepancies among the correlation coefficients can be attributed to the discrepancies in test lengths. It is not clear, however, just how much is artifactual and how much is due to a genuine difference in the way the levels of achievement were estimated.

Additionally, mean information values obtained using the corrected regression equations were typically lower than those obtained with the classical equations. At least part of this difference may be attributable to the shorter test lengths that accompanied the corrected equations, although, again, the extent to which this is true is not known.

Cross-Validation

In this study the regression equations for the inter-subtest branching strategies were developed from data from two different academic quarters. These equations were then applied to the data from the other quarter in a

double-cross-validation design to investigate the extent to which the equations, and hence the inter-subtest branching strategies, were sample-specific. This was done for both the classical and corrected sets of equations.

In terms of test length, the cross-validation groups typically were administered shorter tests than were each of the development groups. This was true in nearly all cases under the .01 termination criterion; results were mixed for the .05 criterion.

The accuracy of measurement, as indexed by the correlation between conventional and adaptive test scores, was not systematically affected by the cross-validation procedure employed here. That is, cross-validating yielded higher correlations about half the time and lower correlations the other half, regardless of whether the classical or corrected equations were used. The precision of measurement (i.e., subtest information) increased slightly under cross-validation over that observed for the development groups, at least for the winter quarter and some of the fall sets of classical equations; results were mixed for the corrected equations.

The increases in accuracy and precision of measurement under cross-validation, though slight, are contrary to expectations, since cross-validating yielded shorter mean test lengths as well. Therefore, the increase in measurement accuracy and precision cannot be accounted for by test length changes.

CONCLUSIONS

The real-data simulation reported here replicated and extended the findings reported by Brown and Weiss (1977). That is, the results from this study show that test length could be reduced by 20%-30% using Brown and Weiss's adaptive testing strategy for achievement testing batteries. Reduced time in testing means more time available to be spent in other activities, such as additional instruction.

The level of reduction in test length depended directly on the size of the termination criterion employed. The termination criteria used here were minimum item information of .05 and .01; Brown and Weiss used a value of .01 in their study. Clearly, the choices for termination were arbitrary, and the results might have been different, depending on the value chosen. More research is needed to determine optimal termination criteria.

The design of this study permitted the separation of the effects due to the intra-subtest item selection procedure from those due to inter-subtest branching. Results from this study show that most of the reduction in test length could be attributed to the adaptive intra-subtest item selection method and variable termination criterion. When this strategy was coupled with inter-subtest branching, an additional reduction in test length of only up to 5% was observed. More research is needed to determine the specific characteristics of the item pool which would contribute to greater reductions in test length when the inter-subtest branching strategies are used.

Achievement level estimates obtained adaptively correlated quite highly with those obtained from a conventional administration of the subtests. It is only when the subtests were very short (less than three items) that low correlations were observed.

As was observed in the Brown and Weiss (1977) study, there was a minimal loss in the amount of psychometric information available in the subtests due to adaptive testing. This was evident in the close correspondence between the information curves for the adaptive and conventional tests.

Perhaps the most important finding from this research was that the regression equations obtained from one set of data could be used to adapt the testing for a different group of students and that the observed test characteristics for this cross-validated group closely paralleled the results obtained from the development group. This result directly reflects what would actually happen in a live-testing implementation of this adaptive testing strategy; that is, the regression equations used for inter-subtest branching would be obtained from one group of students and applied in the testing of a different group of students. This study has shown that such a procedure can be utilized while still maintaining the quality of test characteristics observed for the original group on which the regression equations were developed. Of course, more research is needed to determine the generality of these findings in other situations.

Although this study has replicated and extended some of the findings reported by Brown and Weiss (1977), it was limited by the fact that it, too, was a real-data simulation study. The next step in research on this adaptive testing strategy should be the implementation of this adaptive testing strategy in a live-testing situation, thus enabling researchers to evaluate the validity of the findings from these simulation studies. In addition, more research is needed to determine the generality of these findings across other test batteries and other testing situations.

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APPENDIX: SUPPLEMENTARY TABLES

Table A
Normal Ogive Item Discrimination (*a*), Difficulty (*b*), and Lower Asymptote (*c*) Parameter Estimates for the Fall Quarter Final Exam, by Subtest

Subtest and Item	*a*	*b*	*c*
Chemistry			
1	1.76	.87	.37
2	1.60	-.68	.27
3	1.39	-1.41	.49
4	1.55	.33	.32
5	.77	-.66	.15
6	1.54	-.56	.30
7	-	-	-
8	1.98	-.78	.28
9	2.36	-.60	.23
10	.92	-.93	.30
11	1.66	-1.57	.36
12	-	-	-
13	1.67	.63	.39
Cell			
1	1.48	.63	.43
2	2.53	3.01	.59
3	1.84	1.68	.49
4	1.79	-.28	.32
5	2.08	-.87	.34
6	1.82	-.70	.40
7	2.26	-.48	.54
8	1.17	.12	.51
9	1.58	-1.02	.41
Energy			
1	2.77	.06	.29
2	1.99	-.83	.59
3	2.01	1.41	.43
4	1.68	-.19	.59
5	1.74	1.10	.38
6	2.73	.45	.22
7	2.04	.36	.40
8	2.93	-1.58	.50
9	2.54	-1.26	.34
Reproduction			
1	1.18	0.00	.46
2	1.69	-.76	.40
3	1.47	.54	.49
4	.73	-.24	.34
5	1.40	2.03	.57
6	2.28	-1.36	.61
7	1.08	-.53	.21
8	2.41	-1.05	.25
9	1.79	-.07	.30
10	2.53	-.33	.24
11	1.52	.38	.53
Ecology			
1	1.58	-1.35	.38
2	1.45	-1.19	.47
3	2.36	-1.64	.55
4	1.66	-.33	.36
5	-	-	-
6	1.91	-.14	.41
7	1.42	-.15	.48

Note. Missing entries indicate that the item was rejected in the first phase of item parameter estimation.

Table B
Normal Ogive Item Discrimination (*a*), Difficulty (*b*), and Lower Asymptote (*c*) Parameter Estimates for the Winter Quarter Final Exam, by Subtest

Subtest and Item	*a*	*b*	*c*
Chemistry			
1	1.76	.87	.37
2	-	-	-
3	2.21	-.82	.16
4	1.60	-.68	.27
5	1.26	.66	.37
6	1.55	.33	.32
7	-	-	-
8	1.54	-.56	.30
9	2.36	-.60	.23
10	1.85	-1.50	.29
Cell			
1	1.48	.63	.43
2	1.45	-.20	.30
3	1.84	1.68	.49
4	2.08	-.87	.34
5	1.48	-1.06	.32
6	1.82	-.70	.40
Energy			
1	-	-	-
2	2.20	1.49	.42
3	2.28	-.05	.49
4	2.85	.92	.33
5	2.07	-.49	.68
6	2.73	.45	.22
7	2.09	-.69	.50
8	1.35	-.17	.48
Reproduction			
1	1.14	-.94	.33
2	-	-	-
3	1.47	.54	.49
4	1.40	2.03	.57
5	-	-	-
6	1.30	-.76	.30
7	2.05	-1.01	.53
8	1.85	1.52	.53
9	1.52	.38	.53
Ecology			
1	1.22	-.46	.38
2	-	-	-
3	1.93	1.92	.79
4	2.28	-1.22	.37

Note. Missing entries indicate that the item was rejected in the first phase of item parameter estimation.

Table C

Regression Coefficients and Multiple Correlation Coefficients (R) for the Intermediate Classical Regression Equations from the Fall and Winter Quarter Final Exams

Quarter and Criterion Subtest	Regression Coefficients for Scores on Previously Administered Subtests: Chemistry	Cell	Energy	Reproduction	Regression Constant	R
Fall						
Two Independent Variables						
Energy	.328	.272			-.009	.464*
Reproduction	.286	.228			.203	.434
Ecology	.286	.163			-.392	.415
Three Independent Variables						
Reproduction	.240	.190	.140		.204	.455*
Ecology	.251	.134	.107		-.291	.429
Four Independent Variables						
Ecology	.221	.110	.089	.128	-.029	.446*
Winter						
Two Independent Variables						
Cell	.256		.305		-.144	.525*
Reproduction	.294		.243		.115	.421
Ecology	.140		.085		.120	.244
Three Independent Variables						
Reproduction	.258	.129	.203		.134	.432*
Ecology	.129	.040	.073		.125	.248
Four Independent Variables						
Ecology	.102	.026	.052	.103	.112	.278

Note. An asterisk (*) indicates that the criterion subtest in that particular row was designated as the next subtest to be administered.

Table D
Factor Loadings and Communality Estimates For Maximum Likelihood Factor Analyses of Fall and Winter Quarter Final Exams

Fall Quarter

Two Independent Variables: Criterion Subtest = Energy

$$\Lambda^* \begin{bmatrix}\text{Energy}\\ \text{Chemistry}\\ \text{Cell}\end{bmatrix} = \begin{bmatrix}.594\\ .693\\ .624\end{bmatrix} \qquad h^2 = \begin{bmatrix}.352\\ .481\\ .389\end{bmatrix}$$

Three Independent Variables: Criterion Subtest = Reproduction

$$\Lambda^* \begin{bmatrix}\text{Reproduction}\\ \text{Chemistry}\\ \text{Cell}\\ \text{Energy}\end{bmatrix} = \begin{bmatrix}.552\\ .698\\ .623\\ .590\end{bmatrix} \qquad h^2 = \begin{bmatrix}.304\\ .487\\ .388\\ .348\end{bmatrix}$$

Four Independent Variables: Criterion Subtest = Ecology

$$\Lambda^* \begin{bmatrix}\text{Ecology}\\ \text{Chemistry}\\ \text{Cell}\\ \text{Energy}\\ \text{Reproduction}\end{bmatrix} = \begin{bmatrix}.523\\ .712\\ .611\\ .581\\ .555\end{bmatrix} \qquad h^2 = \begin{bmatrix}.274\\ .506\\ .374\\ .338\\ .309\end{bmatrix}$$

Winter Quarter

Two Independent Variables: Criterion Subtest = Cell

$$\Lambda^* \begin{bmatrix}\text{Cell}\\ \text{Chemistry}\\ \text{Energy}\end{bmatrix} = \begin{bmatrix}.644\\ .701\\ .707\end{bmatrix} \qquad h^2 = \begin{bmatrix}.415\\ .491\\ .501\end{bmatrix}$$

Three Independent Variables: Criterion Subtest = Reproduction

$$\Lambda^* \begin{bmatrix}\text{Reproduction}\\ \text{Chemistry}\\ \text{Energy}\\ \text{Cell}\end{bmatrix} = \begin{bmatrix}.504\\ .717\\ .700\\ .634\end{bmatrix} \qquad h^2 = \begin{bmatrix}.254\\ .542\\ .490\\ .402\end{bmatrix}$$

Four Independent Variables: Criterion Subtest = Ecology

$$\Lambda^* \begin{bmatrix}\text{Ecology}\\ \text{Chemistry}\\ \text{Energy}\\ \text{Cell}\\ \text{Reproduction}\end{bmatrix} = \begin{bmatrix}.303\\ .722\\ .694\\ .628\\ .514\end{bmatrix} \qquad h^2 = \begin{bmatrix}.092\\ .522\\ .481\\ .394\\ .264\end{bmatrix}$$

Table E
Mean Information Values ($\bar{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Chemistry Subtest of the Fall and Winter Quarter Final Exams for the Conventional Test and the Adaptive Test Using Only Intra-Subtest Item Selection with Two Termination Criteria

		Fall						Winter					
				Adaptive Test: Termination Criterion						Adaptive Test: Termination Criterion			
$\hat{\theta}$ Range		Conventional		.01		.05		Conventional		.01		.05	
Lo	Hi	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$
-2.000	-1.800	1	1.25	5	1.11	4	.97	-	-	-	-	-	-
-1.799	-1.600	7	1.56	5	1.66	7	1.56	8	1.21	19	1.31	19	1.30
-1.599	-1.400	19	2.34	19	2.22	18	2.23	22	1.91	22	2.08	22	2.08
-1.399	-1.200	25	2.78	33	2.77	33	2.77	33	2.69	31	2.80	31	2.80
-1.199	-1.000	68	3.78	56	3.77	55	3.77	49	4.05	41	4.03	36	3.96
-0.999	-0.800	64	5.28	55	5.22	57	5.18	77	5.69	68	5.64	65	5.54
-0.799	-0.600	86	6.82	79	6.69	67	6.68	61	6.83	60	6.75	64	6.48
-0.599	-0.400	85	6.92	58	6.98	55	6.97	92	6.52	53	6.48	58	6.39
-0.399	-0.200	79	5.97	84	5.93	64	5.98	67	5.40	96	5.28	73	5.27
-0.199	0.000	40	4.53	56	4.55	58	4.63	57	4.05	69	4.14	78	4.35
0.001	0.200	43	3.50	52	3.46	37	3.32	45	2.87	46	2.85	46	2.85
0.201	0.400	42	3.06	32	3.05	36	3.00	43	2.42	44	2.46	59	2.39
0.401	0.600	41	2.90	84	3.09	95	3.05	104	2.41	103	2.42	91	2.44
0.601	0.800	61	3.23	19	3.16	20	3.15	7	1.00	-	-	7	1.00
0.801	1.000	4	1.27	5	1.28	11	1.39	21	1.44	34	1.38	31	1.55
1.001	1.200	47	1.77	64	1.85	170	2.11	114	2.02	114	2.08	120	2.11
1.201	1.400	88	2.05	94	2.16	13	2.20	-	-	-	-	-	-
1.401	1.600	-	-	-	-	-	-	-	-	-	-	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	4.27	800	4.07	800	3.90	800	3.92	800	3.78	800	3.72

Table F

Mean Information Values ($\overline{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Cell Subtest of the Fall Quarter Final Exam Under all Testing Conditions

				Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
		Conventional Test						Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
$\hat{\theta}$ Range				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	.09	6	.10
-1.799	-1.600	-	-	-	-	-	-	-	-	-	-	7	.26	7	.24	-	-	-	-	14	.23	12	.23
-1.599	-1.400	5	.59	7	.46	7	.46	3	.66	4	.69	16	.45	16	.49	3	.66	4	.69	18	.55	17	.51
-1.399	-1.200	24	1.28	28	1.34	30	1.27	19	1.22	24	1.25	23	1.30	27	1.23	19	1.22	24	1.25	27	1.14	45	1.10
-1.199	-1.000	42	2.19	34	2.27	31	2.25	31	2.12	27	2.23	34	2.17	31	2.25	31	2.12	27	2.23	34	2.09	18	2.15
-0.999	-0.800	52	3.37	58	3.55	57	3.45	41	3.23	40	3.20	41	3.33	41	3.21	41	3.23	40	3.20	42	3.54	48	3.39
-0.799	-0.600	61	4.30	59	4.26	48	4.24	58	4.31	53	4.37	70	4.40	72	4.38	58	4.31	53	4.37	73	4.34	67	4.44
-0.599	-0.400	119	4.82	103	4.78	79	4.76	100	4.74	81	4.74	100	4.74	85	4.86	100	4.74	81	4.74	72	4.77	71	4.83
-0.399	-0.200	61	4.72	68	4.82	51	4.79	81	4.68	65	4.63	70	4.62	54	4.56	81	4.68	65	4.63	62	4.60	43	4.45
-0.199	0.000	23	3.92	30	3.71	30	3.71	46	3.90	30	3.83	45	3.68	40	3.67	46	3.90	30	3.83	65	3.75	53	3.78
0.001	0.200	25	2.52	12	2.07	12	2.07	53	2.74	57	2.79	75	2.88	74	2.88	53	2.74	57	2.79	65	2.93	63	2.93
0.201	0.400	131	2.17	144	2.32	144	2.32	82	2.20	77	2.16	78	2.15	76	2.14	82	2.20	77	2.16	70	2.20	65	2.16
0.401	0.600	20	1.11	16	1.07	1	.83	76	1.66	65	1.67	87	1.70	76	1.69	76	1.66	65	1.68	87	1.70	74	1.71
0.601	0.800	86	1.50	90	1.49	73	1.04	72	1.41	119	1.30	56	1.41	92	1.33	72	1.41	119	1.30	44	1.43	69	1.34
0.801	1.000	34	1.00	33	1.01	237	1.22	51	1.20	77	1.10	46	1.19	64	1.13	51	1.20	77	1.11	31	1.14	54	1.12
1.001	1.200	117	1.09	118	1.11	-	-	57	1.02	81	.99	52	1.03	45	1.01	57	1.02	81	.99	39	1.01	35	.95
1.201	1.400	-	-	-	-	-	-	30	1.02	-	-	-	-	-	-	30	1.02	-	-	29	.95	60	.94
1.401	1.600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	23	1.02	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	2.72	800	2.73	800	2.46	800	2.76	800	2.51	800	2.80	800	2.64	800	2.76	800	2.51	800	2.67	800	2.49

Table G
Mean Information Values ($\bar{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Energy Subtest of the Fall Quarter Final Exam Under all Testing Conditions

$\hat{\theta}$ Range		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
								Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$
-2.000	-1.800	2	1.16	4	1.10	-	-	1	1.17	-	-	5	.61	5	.60	8	.70	5	.57	5	.61	5	.60
-1.799	-1.600	16	2.17	6	1.34	10	1.23	16	2.02	15	2.03	8	2.28	8	2.25	26	2.13	29	2.05	8	2.31	8	2.30
-1.599	-1.400	42	3.44	37	3.37	27	3.30	37	3.33	31	3.21	29	3.56	27	3.54	23	3.31	18	3.22	29	3.56	27	3.54
-1.399	-1.200	28	4.01	25	4.07	21	4.06	14	3.92	12	3.68	25	3.99	19	3.98	25	3.90	21	3.80	25	3.99	19	3.98
-1.199	-1.000	33	3.50	23	3.37	7	3.14	31	3.55	30	3.50	25	3.43	19	3.33	28	3.61	26	3.53	25	3.43	19	3.33
-0.999	-0.800	57	2.67	40	2.87	47	3.03	44	2.67	37	2.68	42	2.67	39	2.72	50	2.62	46	2.64	42	2.67	39	2.72
-0.799	-0.600	74	2.07	55	2.05	54	2.05	58	1.99	44	2.02	43	1.98	42	1.98	53	2.04	44	2.04	43	1.98	42	1.98
-0.599	-0.400	90	1.73	106	1.73	126	1.69	72	1.74	104	1.70	79	1.75	93	1.69	74	1.74	88	1.70	79	1.75	93	1.69
-0.399	-0.200	66	2.11	56	2.29	52	2.31	73	2.11	60	2.06	83	2.12	77	2.04	60	2.15	55	2.14	83	2.12	77	2.04
-0.199	0.000	65	3.51	50	3.26	51	3.24	68	3.48	59	3.43	73	3.45	73	3.64	68	3.49	62	3.52	73	3.45	73	3.64
0.001	0.200	79	5.41	96	5.30	137	5.53	80	5.46	88	5.15	79	5.27	78	5.23	63	5.29	69	5.05	79	5.27	78	5.23
0.201	0.400	43	6.59	61	6.28	11	3.91	43	6.36	31	6.39	54	6.44	44	6.09	47	6.11	33	6.50	54	6.44	44	6.09
0.401	0.600	13	3.83	25	5.21	28	4.90	41	5.94	51	5.71	43	6.09	49	5.87	49	6.06	58	5.90	43	6.09	49	5.87
0.601	0.800	24	4.62	38	4.52	43	4.52	34	4.22	29	4.30	40	4.26	38	4.45	30	4.65	30	4.60	40	4.26	38	4.45
0.801	1.000	41	3.62	19	3.36	20	3.89	27	3.31	34	3.32	26	3.27	27	3.21	28	3.11	28	3.18	26	3.27	27	3.21
1.001	1.200	18	1.70	24	1.68	24	1.68	24	2.09	20	2.03	47	2.20	46	2.17	32	2.30	29	2.31	47	2.20	46	2.17
1.201	1.400	41	2.07	42	1.86	54	2.01	73	2.26	91	2.19	56	2.40	110	2.42	41	2.37	59	2.18	56	2.41	110	2.42
1.401	1.600	68	2.51	93	2.47	88	2.46	58	2.30	58	2.38	43	2.51	6	2.50	49	2.07	48	2.01	43	2.51	6	2.50
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39	1.72	45	1.82	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	3.18	800	3.28	800	3.17	794	3.28	794	3.18	800	3.38	800	3.28	793	3.22	793	3.15	800	3.38	800	3.28

Table H

Mean Information Values ($\bar{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Reproduction Subtest of the Fall Quarter Final Exam Under all Testing Conditions

$\hat{\theta}$ Range		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
								Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	1	.13	1	.37	3	.16	3	.32	1	.21
-1.799	-1.600	10	.85	4	.82	5	.85	1	.98	2	.53	6	.86	6	.72	9	.75	7	.73	7	.61	9	.63
-1.599	-1.400	11	1.68	14	1.72	11	1.70	16	1.55	14	1.51	16	1.54	15	1.55	16	1.64	14	1.59	22	1.49	19	1.52
-1.399	-1.200	30	3.01	23	2.77	25	2.68	17	2.94	20	2.97	24	3.11	23	3.06	23	3.02	23	3.00	23	3.06	26	3.17
-1.199	-1.000	44	4.33	48	4.30	51	4.25	38	4.32	39	4.29	40	4.30	40	4.20	35	4.24	38	4.18	33	4.18	31	4.12
-0.999	-0.800	43	4.78	43	4.82	29	4.79	43	4.70	33	4.74	33	4.75	28	4.73	28	4.86	24	4.86	32	4.85	24	4.84
-0.799	-0.600	33	5.01	25	5.00	18	4.97	26	5.06	15	4.88	30	5.08	18	5.06	30	5.03	17	5.07	27	4.99	20	5.01
-0.599	-0.400	26	5.34	20	5.27	22	5.37	27	5.47	23	5.42	22	5.45	21	5.46	31	5.53	27	5.53	31	5.53	29	5.51
-0.399	-0.200	44	5.84	66	5.98	62	6.02	59	6.01	51	5.98	66	5.94	60	5.91	57	5.93	46	5.85	66	5.90	56	5.91
-0.199	0.000	71	5.75	71	5.66	67	5.63	54	5.64	60	5.71	60	5.68	58	5.72	59	5.82	69	5.80	57	5.73	64	5.76
0.001	0.200	90	4.66	92	4.66	103	4.67	81	4.82	84	4.80	81	4.77	88	4.75	75	4.75	77	4.78	71	4.82	72	4.81
0.201	0.400	85	3.81	64	3.51	66	3.53	95	3.69	104	3.68	89	3.67	98	3.67	99	3.70	111	3.70	100	3.71	108	3.67
0.401	0.600	130	3.01	126	3.20	127	3.22	109	3.03	104	3.02	105	3.05	102	3.03	85	3.02	72	2.98	79	3.10	75	3.05
0.601	0.800	11	2.36	20	2.44	19	2.60	57	2.48	56	2.48	53	2.49	46	2.51	82	2.38	78	2.39	81	2.40	74	2.41
0.801	1.000	52	1.70	57	1.67	23	1.19	43	1.82	55	1.78	45	1.79	59	1.78	43	1.85	47	1.88	36	1.83	51	1.79
1.001	1.200	55	1.15	127	1.22	172	1.36	58	1.38	78	1.26	53	1.40	79	1.28	32	1.36	55	1.30	40	1.39	53	1.28
1.201	1.400	65	1.24	-	-	-	-	53	.97	36	.87	55	.94	32	.87	47	1.00	27	.98	40	1.02	23	.94
1.401	1.600	-	-	-	-	-	-	23	.78	26	.82	22	.80	26	.82	22	.66	40	.66	30	.68	40	.68
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	.63	25	.60	22	.63	23	.63
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	3.59	800	3.61	800	3.55	800	3.52	800	3.42	800	3.53	800	3.44	800	3.46	800	3.36	800	3.47	800	3.38

Table I
Mean Information Values ($\bar{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Ecology Subtest of the Fall Quarter Final Exam Under all Testing Conditions

								Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
		Conventional Test		Adaptive Intra-Subtest Item-Selection: Termination				Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
$\hat{\theta}$ Range				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$
-2.000	-1.800	11	1.05	3	.97	3	.97	4	.81	4	.81	1	1.13	1	1.12	5	1.05	3	.97	-	-	1	1.27
-1.799	-1.600	25	1.86	10	1.72	10	1.72	8	1.80	7	1.79	8	1.75	6	1.68	12	1.79	11	1.79	4	1.53	3	1.61
-1.599	-1.400	24	2.20	34	2.33	23	2.30	25	2.30	25	2.31	19	2.35	20	2.34	18	2.27	21	2.27	15	2.34	16	2.35
-1.399	-1.200	16	2.40	15	2.37	13	2.35	23	2.36	22	2.33	21	2.42	17	2.34	27	2.37	25	2.37	24	2.41	16	2.41
-1.199	-1.000	42	2.15	30	2.15	30	2.14	29	2.17	28	2.14	28	2.18	28	2.15	33	2.21	33	2.15	22	2.17	18	2.12
-0.999	-0.800	24	1.94	40	1.97	35	1.98	37	2.00	33	2.00	40	1.97	37	1.97	38	2.01	37	1.99	38	1.99	36	1.99
-0.799	-0.600	77	2.01	83	2.03	81	2.03	76	1.95	70	1.95	80	1.99	75	2.00	72	1.92	59	1.93	62	1.99	54	2.00
-0.599	-0.400	41	2.03	35	2.01	20	1.86	55	2.27	55	2.78	52	2.18	55	2.22	56	2.31	58	2.30	61	2.20	64	2.18
-0.399	-0.200	148	2.66	148	2.63	158	2.55	104	2.69	100	2.65	150	2.68	153	2.64	90	2.68	85	2.64	94	2.66	92	2.63
-0.199	0.000	32	2.98	32	2.96	33	2.92	63	2.82	67	2.80	31	2.83	33	2.82	68	2.77	71	2.78	100	2.85	105	2.82
0.001	0.200	-	-	-	-	-	-	29	2.22	27	2.25	20	1.76	16	1.77	45	2.47	45	2.47	13	2.43	11	2.51
0.201	0.400	1	.55	2	.71	10	.78	64	1.76	67	1.78	114	1.75	135	1.71	61	1.83	68	1.83	46	1.65	49	1.63
0.401	0.600	103	.90	107	.92	104	.98	106	1.30	108	1.24	208	1.36	199	1.32	78	1.31	70	1.22	122	1.29	136	1.25
0.601	0.800	254	.97	261	.95	280	1.03	109	.85	108	.83	28	1.07	25	1.06	64	.84	69	.81	140	.88	133	.83
0.801	1.000	-	-	-	-	-	-	68	.55	79	.55	-	-	-	-	73	.56	71	.53	59	.59	66	.59
1.001	1.200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	46	.31	65	.30	-	-	-	-
1.201	1.400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	.22	6	.25	-	-	-	-
1.401	1.600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		798	1.70	800	1.69	800	1.67	800	1.80	800	1.77	800	1.95	800	1.93	797	1.78	797	1.73	800	1.80	800	1.76

Table J

Mean Information Values ($\overline{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Cell Subtest of the Winter Quarter Final Exam Under all Testing Conditions

								Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
$\hat{\theta}$ Range				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	.18	-	-
-1.799	-1.600	-	-	-	-	-	-	-	-	-	-	4	.33	2	.38	-	-	-	-	13	.34	16	.32
-1.599	-1.400	15	.68	21	.67	21	.67	4	.52	4	.57	24	.69	25	.70	4	.52	4	.57	36	.65	26	.64
-1.399	-1.200	38	1.39	34	1.31	34	1.31	39	1.29	38	1.30	43	1.19	43	1.17	39	1.29	38	1.30	35	1.25	44	1.17
-1.199	-1.000	51	2.12	64	2.26	64	2.26	39	2.06	38	2.06	48	2.16	48	2.15	39	2.06	38	2.06	52	2.20	49	2.17
-0.999	-0.800	83	3.17	68	3.16	67	3.17	71	3.08	71	3.06	66	3.11	65	3.10	71	3.08	71	3.06	61	3.05	61	3.01
-0.799	-0.600	68	3.52	65	3.48	56	3.48	65	3.45	59	3.45	78	3.43	66	3.44	65	3.45	59	3.45	74	3.51	65	3.58
-0.599	-0.400	66	3.30	69	3.25	53	3.47	80	3.26	69	3.21	92	3.40	97	3.32	80	3.26	69	3.21	86	3.38	86	3.30
-0.399	-0.200	81	3.00	81	2.99	98	2.88	96	2.88	99	2.90	84	2.81	82	2.89	96	2.88	99	2.90	79	2.81	81	2.85
-0.199	0.000	102	2.40	94	2.38	94	2.38	75	2.19	73	2.19	78	2.19	80	2.18	75	2.19	73	2.19	83	2.14	76	2.20
0.001	0.200	59	1.67	104	1.70	104	1.70	91	1.78	88	1.79	77	1.70	78	1.71	91	1.78	88	1.79	70	1.74	68	1.71
0.201	0.400	42	1.53	1	.24	1	.24	48	1.38	53	1.39	60	1.41	58	1.42	48	1.38	53	1.39	62	1.42	65	1.45
0.401	0.600	71	1.21	80	1.14	15	.69	56	1.14	45	1.11	57	1.20	62	1.19	56	1.14	45	1.11	43	1.22	42	1.19
0.601	0.800	32	.82	27	.85	193	1.08	50	1.11	97	1.06	41	1.14	59	1.08	50	1.11	97	1.06	35	1.10	61	1.06
0.801	1.000	92	1.02	92	1.03	-	-	34	1.01	26	.84	20	1.02	18	.91	34	1.01	26	.84	29	1.00	19	.92
1.001	1.200	-	-	-	-	-	-	52	.90	40	.89	28	.92	17	.91	52	.90	40	.89	11	.86	10	.81
1.201	1.400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	29	.90	31	.87
1.401	1.600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	2.18	800	2.15	800	2.12	800	2.13	800	2.08	800	2.18	800	2.15	800	2.13	800	2.08	800	2.11	800	2.07

Table K
Mean Information Values ($\bar{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Energy Subtest of the Winter Quarter Final Exam Under all Testing Conditions

$\hat{\theta}$ Range		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
								Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$	N	$\bar{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-1.799	-1.600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	.01	3	.01	-	-	-	-
-1.599	-1.400	-	-	-	-	-	-	10	.06	4	.05	2	.06	-	-	39	.04	30	.03	2	.06	-	-
-1.399	-1.200	20	.18	24	.16	3	.21	33	.14	31	.13	17	.15	16	.18	31	.14	39	.13	17	.15	16	.18
-1.199	-1.000	55	.47	51	.42	72	.33	64	.42	56	.35	43	.42	42	.36	70	.43	63	.37	43	.42	42	.36
-0.999	-0.800	87	.94	77	.86	77	.86	72	.91	87	.86	81	.90	83	.90	63	.92	74	.90	81	.90	83	.91
-0.799	-0.600	88	1.53	85	1.45	80	1.44	73	1.57	74	1.58	67	1.56	67	1.56	78	1.57	71	1.57	67	1.56	67	1.56
-0.599	-0.400	111	2.21	91	2.09	56	2.00	91	2.13	93	2.18	88	2.17	91	2.18	72	2.16	81	2.18	88	2.17	91	2.18
-0.399	-0.200	55	2.28	65	2.40	147	2.44	68	2.51	70	2.49	84	2.53	87	2.50	62	2.51	62	2.48	84	2.53	87	2.50
-0.199	0.000	93	2.82	133	2.91	77	2.82	85	2.68	59	2.68	98	2.71	70	2.76	76	2.61	54	2.61	98	2.71	70	2.76
0.001	0.200	54	3.11	34	2.58	34	2.58	48	2.91	64	3.04	58	3.00	81	3.04	44	2.99	58	2.90	58	3.00	81	3.04
0.201	0.400	14	3.00	80	4.12	79	4.15	68	4.15	54	3.95	61	3.99	48	3.80	50	4.16	42	4.03	61	3.99	48	3.80
0.401	0.600	70	4.50	18	1.82	19	1.78	46	4.23	50	4.22	59	4.21	59	4.31	51	4.42	53	4.56	59	4.21	59	4.31
0.601	0.800	19	2.40	28	4.62	36	4.37	24	3.67	27	3.55	26	4.18	30	3.65	35	4.17	39	3.91	26	4.18	31	3.70
0.801	1.000	35	3.74	11	2.12	10	2.16	25	3.78	25	3.80	29	3.45	28	3.96	22	3.92	19	3.89	29	3.45	27	3.92
1.001	1.200	43	2.86	46	2.79	53	3.13	31	2.95	32	3.38	33	3.62	44	3.39	24	3.44	26	3.74	33	3.62	44	3.39
1.201	1.400	56	3.02	18	3.02	18	3.02	33	2.79	45	2.74	38	2.80	54	2.96	32	2.56	34	2.54	38	2.80	54	2.96
1.401	1.600	-	-	39	2.77	39	2.77	29	2.49	29	2.53	16	2.77	-	-	21	2.02	35	2.06	16	2.77	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24	1.94	17	1.99	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	2.34	800	2.30	800	2.31	800	2.32	800	2.33	800	2.51	800	2.52	800	2.22	800	2.22	800	2.51	800	2.52

Table L
Mean Information Values ($\overline{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Reproduction Subtest of the Winter Quarter Final Exam Under all Testing Conditions

$\hat{\theta}$ Range		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
								Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	.22	2	.22	2	.20	1	.20
-1.799	-1.600	16	.43	16	.43	16	.43	2	.38	2	.38	11	.37	10	.37	10	.35	8	.34	14	.32	15	.32
-1.599	-1.400	4	.44	4	.44	4	.44	22	.61	22	.61	20	.61	21	.60	22	.55	25	.55	25	.57	24	.57
-1.399	-1.200	54	1.13	57	1.14	57	1.14	23	1.09	21	1.11	31	1.08	28	1.09	27	1.11	23	1.15	25	1.10	23	1.12
-1.199	-1.000	30	1.59	31	1.72	29	1.74	31	1.60	33	1.59	25	1.66	28	1.61	27	1.62	30	1.61	36	1.63	37	1.60
-0.999	-0.800	72	2.04	21	1.82	15	1.65	45	1.99	27	1.94	65	2.03	47	2.02	58	2.03	50	2.02	63	2.04	45	1.98
-0.799	-0.600	82	2.06	116	2.08	131	2.05	75	2.10	77	2.05	67	2.04	78	2.02	75	2.06	66	2.00	67	2.05	76	2.04
-0.599	-0.400	42	1.76	33	1.77	12	1.71	66	1.83	69	1.81	60	1.85	51	1.81	56	1.81	63	1.81	51	1.83	56	1.78
-0.399	-0.200	62	1.59	70	1.60	70	1.60	61	1.51	56	1.51	64	1.48	64	1.50	72	1.52	63	1.51	73	1.51	62	1.51
-0.199	0.000	81	1.25	25	1.08	25	1.08	84	1.31	81	1.30	87	1.32	83	1.32	74	1.31	73	1.31	78	1.32	75	1.32
0.001	0.200	92	1.30	147	1.31	147	1.31	82	1.28	75	1.28	70	1.28	69	1.28	75	1.27	67	1.27	67	1.28	60	1.28
0.201	0.400	5	.94	9	.90	2	.54	62	1.32	60	1.31	55	1.32	57	1.30	63	1.32	69	1.30	62	1.31	72	1.30
0.401	0.600	56	1.26	38	1.32	57	.89	34	1.29	51	1.28	37	1.27	61	1.30	35	1.32	40	1.31	33	1.29	50	1.32
0.601	0.800	86	1.25	119	1.22	235	1.33	67	1.30	72	1.26	74	1.29	72	1.25	56	1.30	53	1.27	58	1.33	52	1.27
0.801	1.000	118	1.21	114	1.23	-	-	50	1.15	45	1.12	45	1.17	28	1.09	40	1.19	39	1.13	43	1.14	31	1.10
1.001	1.200	-	-	-	-	-	-	47	1.09	93	1.01	47	1.09	85	1.02	35	1.05	71	.99	31	1.08	73	1.00
1.201	1.400	-	-	-	-	-	-	38	1.11	9	1.15	30	1.10	12	1.16	32	1.12	17	1.12	32	1.11	16	1.09
1.401	1.600	-	-	-	-	-	-	11	1.29	7	1.22	12	1.28	6	1.21	23	1.15	28	1.13	24	1.17	19	1.12
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	1.28	13	1.28	16	1.30	13	1.30
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	1.44	800	1.43	800	1.42	800	1.43	800	1.38	800	1.42	800	1.39	800	1.42	800	1.38	800	1.41	800	1.38

Table M
Mean Information Values ($\overline{I}$) at Estimated Achievement Level ($\hat{\theta}$) Intervals for the Ecology Subtest of the Winter Quarter Final Exam Under all Testing Conditions

$\hat{\theta}$ Range		Conventional Test		Adaptive Intra-Subtest Item Selection: Termination				Adaptive Intra-Subtest Item Selection with Inter-Subtest Branching															
								Classical Equations								Corrected Equations							
								Fall: Termination				Winter: Termination				Fall: Termination				Winter: Termination			
				.01		.05		.01		.05		.01		.05		.01		.05		.01		.05	
Lo	Hi	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$	N	$\overline{I}$
-2.000	-1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	.18	-	-	-	-	-	-
-1.799	-1.600	-	-	-	-	-	-	6	.47	5	.53	-	-	-	-	9	.32	14	.35	-	-	-	-
-1.599	-1.400	21	.86	21	.83	21	.83	19	1.00	18	.94	11	1.07	10	1.07	27	1.00	23	1.01	4	1.12	4	1.13
-1.399	-1.200	79	1.52	79	1.48	-	-	51	1.67	52	1.66	52	1.72	53	1.72	34	1.61	35	1.60	24	1.61	24	1.62
-1.199	-1.000	-	-	-	-	-	-	21	1.98	2	1.91	37	1.96	24	1.94	29	1.98	12	1.97	68	1.97	33	1.95
-0.999	-0.800	-	-	-	-	-	-	11	1.69	11	1.68	-	-	-	-	14	1.71	14	1.71	1	1.92	-	-
-0.799	-0.600	44	1.16	44	1.16	44	1.16	20	1.29	20	1.29	27	1.27	28	1.26	26	1.23	25	1.19	11	1.19	11	1.19
-0.599	-0.400	-	-	-	-	-	-	23	.82	20	.80	16	1.01	15	1.01	51	.91	51	.92	26	.98	25	.99
-0.399	-0.200	-	-	-	-	-	-	49	.64	51	.65	18	.35	16	.31	76	.73	75	.73	14	.49	14	.54
-0.199	0.000	-	-	-	-	-	-	118	.59	116	.59	154	.57	147	.57	113	.60	101	.60	50	.49	51	.48
0.001	0.200	27	.07	26	.05	26	.05	175	.48	212	.46	311	.49	367	.47	114	.48	136	.47	186	.47	242	.45
0.201	0.400	629	.38	630	.37	709	.38	146	.37	134	.35	164	.38	140	.36	100	.37	102	.34	221	.38	210	.35
0.401	0.600	-	-	-	-	-	-	111	.28	105	.27	10	.32	-	-	88	.28	83	.27	152	.28	144	.27
0.601	0.800	-	-	-	-	-	-	50	.20	54	.20	-	-	-	-	62	.19	73	.20	43	.20	42	.21
0.801	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	36	.14	41	.14	-	-	-	-
1.001	1.200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19	.11	15	.11	-	-	-	-
1.201	1.400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.401	1.600	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.601	1.800	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.801	2.000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Group		800	.54	800	.52	800	.42	800	.62	800	.57	800	.67	800	.64	800	.63	800	.58	800	.59	800	.51

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